NUCLEAR ENGINEERING VOL. 6 NO. 67 DECEMBER, 1961

Anchors A-Weigh?

AT long last the Minister of Transport has been able to announce in the House, a Government decision regarding the future of nuclear ship propulsion development. Even after his statement, however, it was still not entirely clear whether this was a case of " up-anchor " or " up-gangway " and Members seemed surprisingly reluctant to probe. This was probably because the main issue was whether one of the commercial tenders (so long since prepared) was to be taken up now with the Ministry financing the construction of a nuclear ship. The answer to this is unequivocably no—at least not in the predictable future.

In spite of the heavy pressures and the persuasive arguments (concerned mainly with the thesis that only by experience shall we be able to tell, only by building shall we know the real problems, the real costs, etc.) the Government has held firm. It is more than two years since the Prime Minister indicated that the Government policy would be " no prestige construction "—a policy we have supported throughout—but in view of the unguarded promises made at the last election to subsidize a replacement for the " Queens " and the subsequent maladroit handling in Parliament, added to the very real concern over the future of the shipbuilding industry in the face of world competition, it would have been understandable if the Government's resolution had faltered and some awkward compromise, short-term development instituted. Happily commonsense has prevailed and the Government is not to be coerced.

The bare statement that the Minister was to authorize " a vigorous programme of research aimed at a reactor system which is economically attractive . . . and carried out by the Atomic Energy Authority in conjunction with industry," on the face of it gave little cause for satisfaction. Was this not after all implied in the original Atomic Energy Act? quite apart from such references as the last U.K.AEA Annual Report. But, in this instance it would seem that the parliamentary statement does the Government less than justice and the practical steps that are being taken to organize future developments are genuinely constructive.

The most important of these is the establishment of a small, technically competent committee (to replace the unwieldy Numarcom) under the Permanent Secretary to the Ministry of Transport but answerable jointly to the Minister of Transport and the Minister for Science to advise the Ministers on the course of future developments. The committee will consist of representatives from the U.K.AEA, the shipbuilders, the shipowners and an independent authority with both marine and nuclear engineering experience. It is deliberately small, compact and, we can expect, strong, with flexible terms of reference in regard to executive powers. It would seem that the Minister has established in effect a board which can take responsibility and, working through the AEA, see that appropriate action results. If there is cause for dissatisfaction with the policy or the progress of the U.K.AEA as its principal contractor remedial action can be taken at the highest levels.

The most important, immediate task of the committee will be to ensure that any reactor development programme that is instituted recognizes the effort that industry has already made and allows industrial interests a fair proportion of the work. This can be no Calder Hall type of development in which industry waits for the Authority to pronounce—or indeed, an AGR or DFR exercise. In the first place the U.K.AEA does not command sufficient experience on the specifically ship aspects of the development and in the second place industry can no longer be thought of simply as a body of sub-contracting fabricators; its potential design and research abilities must be fully used.

Whilst it is probable that the committee will not be anxious to select a reactor system at the present time, there seems little doubt that the steam-cooled heavy-water reactor will be given solid impetus and the U.K.AEA's land-based studies integrated with the Rolls-Royce/Vickers effort (*Nuclear Engineering*, June, 1961). We expect in fact to see this system now vigorously pursued. The OMR has fallen rather out of favour of late in the U.K. in spite of rising interest outside (see the review in this issue) but the U.K. can look forward to participating in the Euratom organic projects and through both Dragon and its own work is active in the HTR field, so, the SCHWR system is clearly the system of principal interest at this point. Stimulus will no doubt be added to the light-water reactor programme now taking shape within the Reactor Group but the American work in this field and the proposed ENEA/Vulcain project would seem to indicate that PWRs at least are well covered if not BWRs.

This is not to suggest that studies should be concentrated entirely on steam cooling. There are many interesting fields of exploration open and plenty of opportunity for advance. Only let the U.K. be sure it extracts the maximum benefit from its collaboration agreements and does not repeat work that has already been done elsewhere. There are, of course, also many areas of research of fundamental importance to a wide range of systems, in particular, plutonium burning and where a marine application raises different emphases from a land-based use. At this point in time the accent needs to be on breadth and flexibility.

No doubt this undramatic approach to ship development will be received with disapprobation in many quarters and we have, of course, yet to see demonstrated that the organization being set up will really get something done. One must also regret the years required to make the decisions, but so far so good; objectives and methods are defined, let action follow.

BNES Created

THE dissolution of the British Nuclear Energy Conference and the creation in its place of the British Nuclear Energy Society has now been formally announced. The BNEC was inaugurated at the end of 1955 by the five senior institutions (Civils, Mechanicals, Electricals, Chemicals and Physics) with the principal object of preventing any new competitive institution being born at a time when the academic significance of this new technology could not be forecast, nor the general effect of the development programme upon the progress of the more conventional disciplines. To begin with the BNEC was entirely successful in its aims and could claim credit for the organization of the Calder Hall symposium and for co-ordinating a number of other meetings at which atomic energy discussions crossed the boundaries of interest of more than one institution.

Once the glamour, however, had begun to wear off atomic energy, the BNEC ceased to exercise any significant function and, indeed, was something of an embarrassment, particularly when it was necessary to hold discussions at a high level with other countries such as the United States, in which there existed a well organized, energetic nuclear society. Even its principal function of preventing the formation of a competitive institution became no longer viable when the Institution of Nuclear Engineers made its hesitant appearance.

The new Society which comes into being on January 1 is a complete break with the past and is a real attempt to provide an organization more in keeping with the modern trend towards an integration of techniques rather than the division into individual disciplines which became the practice in the first half of this century. The BNES quite deliberately is not another vertical organization but is a horizontal organization providing a platform for the existing disciplines to meet together to discuss and to exchange experiences. Present members of the original constituent bodies (these are the twelve former collaborators in the BNEC, four of whom are associated in the Joint Panel on Nuclear Marine Propulsion) may join the Society as of right, but whilst it is intended that a high standard of academic achievement and attainment should form the basis of the Society's activities, its aim is to envelop all those who are genuinely interested in nuclear energy and members of other societies or independent people may join through appropriate channels. Indeed, it is very much the intention that the scientific and technical members should be joined by representatives of such relevant professions and practices as Accountancy, Law, Medicine, Insurance and the like.

Atomic energy developments have shown more clearly than any other the necessity for the physicist, metallurgist, engineer, etc., to work together, to understand each other's arts and to integrate their efforts with the financier, the insurer and so on. The BNES is a real attempt to serve the new needs and we believe it may well form a pattern for other similar societies designed to cut across the traditional and often arbitrary distinctions between men of progress.

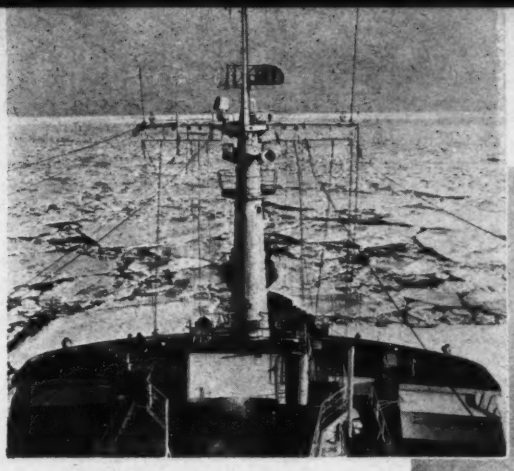
Its conception and its promotion are very largely the work of Sir Leonard Owen, Member for Production and Engineering of the U.K.AEA. He was due to retire from the Authority next spring and would thus have been in a position to concentrate on the nursing of this new baby. He is not, however, to be let go by the Authority immediately and is to remain a part-time member and will continue to chair the management boards of the Production and Engineering Groups. Nevertheless, he will devote a great deal of effort to the project and as the 1960 President of the BNEC who takes over as first President of the BNES we wish him and the new organization every success.

Oldbury in Concrete

IT seems highly likely that the CEGB will break the regular succession of contracts for nuclear power stations and will award the contract for Oldbury to The Nuclear Power Group, already constructing Berkeley, Bradwell and Dungeness in addition to Latina in Italy. The unlucky contestants are the United Power Company, the recent association of Atomic Power Constructions and GEC who between them are responsible for Hunterston, Trawsfynydd and Tokai Mura in Japan. As the English Electric, Taylor Woodrow, Babcock and Wilcox Group received the contract for the station immediately preceding Oldbury (Sizewell) they could never be regarded as serious contenders in the race. The present evidence, which has always been conclusive in the past, is that TNPG have received a detailed questionnaire from the Board while the other contenders have not. There is also the equally reliable Thames-side gossip which has unofficially handed the laurels to TNPG while heart searching has begun at UPC.

A possible prime reason for the award is the more accurate gauging by TNPG of the CEGB's attitude towards a concrete vessel. Whereas UPC (tendering basically from APC experience), having done a preliminary study, decided to place nearly all its weight on a steel pressure vessel, giving much less attention to the concrete design which was also submitted, TNPG put all its efforts into a concrete design and this won the Board's approval No details have yet been announced of TNPG's design but there is little doubt that the price that TNPG have been able to offer is lower than UPC were able to quote with their steel (or for that matter for their concrete) vessel and the initial contract price may not be very far from £89 per kilowatt, making the capital cost of the station close to £100/kW when all the CEGB charges have been taken into account.

Experience in this country with concrete in this type of application is small and it is ironic that two years ago the only experience in concrete pressure vessel work was in the GEC, Simon-Carves Group. It has been suggested that in fact there has been a certain over-optimism in TNPG's estimates (as with the first steel stations) and some escalation of the initial quotations may be necessary. Indeed, the final price may be slightly higher than the ultimate possible with the steel pressure vessel, but it is in the interests of the industry as a whole that the Generating Board should be prepared to experiment, to investigate new techniques and allow industry to depart from the accepted. Only if the CEGB is prepared to experiment in the same way as overseas utilities can a corresponding improvement in technology be ensured.



The *Lenin* in operation in the Arctic. She is being used to land a team of scientists on a floating survey station and the establishment of 16 automatic radiometeorological stations for checking direction and flow of drifting ice.

World Digest

International

The Belgian Vulcain reactor project has been selected by the ENEA study group on ship propulsion for further study with a view to establishing an outline for a joint research programme including the time scale and expenditure. Developments in other reactor systems will be kept under review. The study group at their meeting held during early October also decided to make a more detailed examination of the three ship types considered suitable for nuclear propulsion—a bulk carrier, a tanker, and an oceanographic vessel. It was also agreed to set up a group of experts to examine the legal problems involved in the joint ship construction and operation.

Draft of a treaty providing for the exchange of nuclear information between Euratom and the Argentine has been approved by the Euratom Council of Ministers. Similar to the agreement concluded with Brazil ("World Digest," July, 1961), the Argentine treaty will be for 20 years and is designed also to promote general technical co-operation and the exchange of students.

A troika for directing Euratom's research programme is being considered, according to Professor Felice Ippolito, general secretary of the CNEN, Italy, and a member of the Community's research committee. Speaking in London at a meeting arranged by Britain in Europe on November 7, he said it was thought that the responsibility attached to administering the programme, particularly if, as planned, some $400-500 million were involved, was too great for one man. The solution, he said, would be to replace him with three men with equal powers.

M. Etienne Hirsch, president of Euratom, M. H. Krekeler and M. E. Sassen, Euratom Commissioners, have been visiting Japan in order to obtain a first-hand view of the country's progress in the nuclear energy field. The visit follows that of the chairman of the J.AEC to Brussels in June.

September 10-14, 1962, have been named as the dates for the first Foratom congress. It will be held in Paris and the first two days will be devoted to visits to French nuclear installations. The congress will take place a few days before the IAEA annual conference, scheduled for September 18-28, and it is hoped to attract delegates to this to Paris.

More Collaboration Sought

THE setting up of an international high flux reactor project within the framework of a national nuclear programme was foreseen at the recent meeting of top-level experts convened by ENEA to discuss international co-operation in various nuclear fields. This was one way in which it was agreed that closer collaboration between different countries could be achieved. Another was the setting up of a committee such as the European-American Nuclear Data Committee for dealing with reactor physics. For more immediate action it was proposed by the group that a detailed examination should be made of current knowledge, problems and requirements by experts working in the fields concerned (reactor physics, direct conversion of nuclear to electrical energy, electronic computation and data processing, advanced reactor types and very high flux reactors). This proposal will be considered by the ENEA steering committee due to meet in Paris early December. The top-level experts, the meeting of whom had been inspired by Dr. L. Kowarski's paper on "New Trends in Atomic Research and their International Significance," came from 13 European countries, the U.S.A., Canada and Euratom.

SENA'S proposal for the 242 MW(e) PWR at Chooz, France (*Nuclear Engineering*, November, 1961, p. 465), has been formally submitted to the U.S.-Euratom Joint Reactor Board in response to the second round invitation for projects to be built under the terms of the U.S.-Euratom reactor programme ("World Digest," November, 1961, p. 447).

Pleas for greater participation by the IAEA in promoting international co-operation ended the symposium on programming and utilization of research reactors held under the auspices of the Agency in Vienna, October 16-21. They came from member countries of all political shades, including the U.K., U.S.A. and U.S.S.R. Russia's Dr. V. Goncharev suggested that the Agency collect and disseminate necessary information on research reactors that would help developing countries in choosing the type best suited to their requirements. The Agency should also prepare a general programme of research for such reactors. Dr. J. F. Hill, of the U.K., thought that the IAEA should promote international exchange agreements related to reactor experience, a suggestion supported by Dr. T. Thompson, of America. The symposium was attended by 200 delegates from 35 countries, ENEA and Euratom. Sixty-nine papers were presented.

As anticipated no attempt was made at the recent five-day IAEA symposium on power reactor experiments to make comparisons between the merits of different reactor types. This was because most of those described were scientifically advanced but relatively untested. Drawing attention to this, M. Pierre Balligand, IAEA deputy director general for technical operations, said it was nevertheless encouraging to note the extent to which the technology of nuclear reactors had advanced and how many new roads had been opened to the solution of the outstanding problems.

United Kingdom

Asked in the House of Commons to make a statement about the Admiralty's plans regarding nuclear-propelled vessels, Mr. Orr-Ewing, the Civil Lord of the Admiralty, said that a second nuclear submarine had been ordered—the *Valiant*—and that it was hoped in due course she would give her name to a class of nuclear submarine equipped with British machinery. The *Valiant* was in fact ordered in August, 1960, when the Admiralty stated that Vickers-Armstrongs, who are building *Dreadnought*, had been authorized to put the work in hand. To date the keel has not been laid. The Admiralty state, however, that there is no delay; that some prefabrication work was carried out on some submarines before the keel was laid, and this was probably what was happening in the case of the *Valiant*. In the meantime, work on the *Dreadnought* is being delayed by a strike by 50 fitter members of the AEU, arising from a pay dispute of long standing. The local liaison safety committee referred to last month has been formed and its members assured of the inherent safety of the *Dreadnought* system.

Installation in Northern Ireland of even a small power reactor for electricity generation was not envisaged in the near future, Mr. John Andrews, Minister of Commerce, told the Ulster House of Commons recently. Replying to a question by Mr. Kirk he said that he had been advised that the use of nuclear power for generating purposes was at present not economically justified, but its possibilities were kept constantly under review. He then reiterated a statement made by Mr. Richard Wood, the U.K. Minister of Power, when visiting Belfast, that power stations of the type being built in England and Wales would be unsuitable for Northern Ireland.

Laying of the graphite in No. 1 reactor at Hinkley Point is well under way. There will be 2 475 t of it when the reactor is ready for operation. Fuel loading is expected to start in the spring of 1963.

Work by the AEA Reactor Group on marine propulsion is to be intensified. At the same time there will be close liaison with the ship-building industry and the Ministry of Transport. The Authority announced this following the disclosure in the House of Commons on November 8 by Mr. Ernest Marples, Minister of Transport, that the Government had decided not to build a nuclear-powered ship at present but to concentrate on a vigorous programme of research. Mr. Marples announced the decision in reply to a question put by Mr. Wall. The decision had been made in light of the advice given by the Committee on the Application of Nuclear Power for Marine Purposes (NUMARCOM) and its technical committee after their appraisal of the five tenders submitted for a nuclear ship. It is believed that a smaller committee than NUMARCOM will be responsible for future liaison between the parties concerned (see page 501).

A High Court case not dissimilar in aspect and possible repercussions to the Mme. Majoni case reported in our previous issue is pending. It concerns the claim of the dependants of a former Windscale worker that he was injured by ionizing radiations. Mr. Bernard Clarke, who died last December, suffered from myeloid leukæmia and cataract in both eyes. Proceedings against the AEA were first instituted in 1957.

After six years the British Nuclear Energy Conference is to cease to function. It is being replaced on January 1, 1962, by the British Nuclear Energy Society, membership of which will be open to members of the constituent societies of the BNEC and to other people who are actively engaged in the professional, scientific and technical aspects of nuclear energy and ancillary subjects. (Comment on the formation of the society is made on page 502 of this issue.)

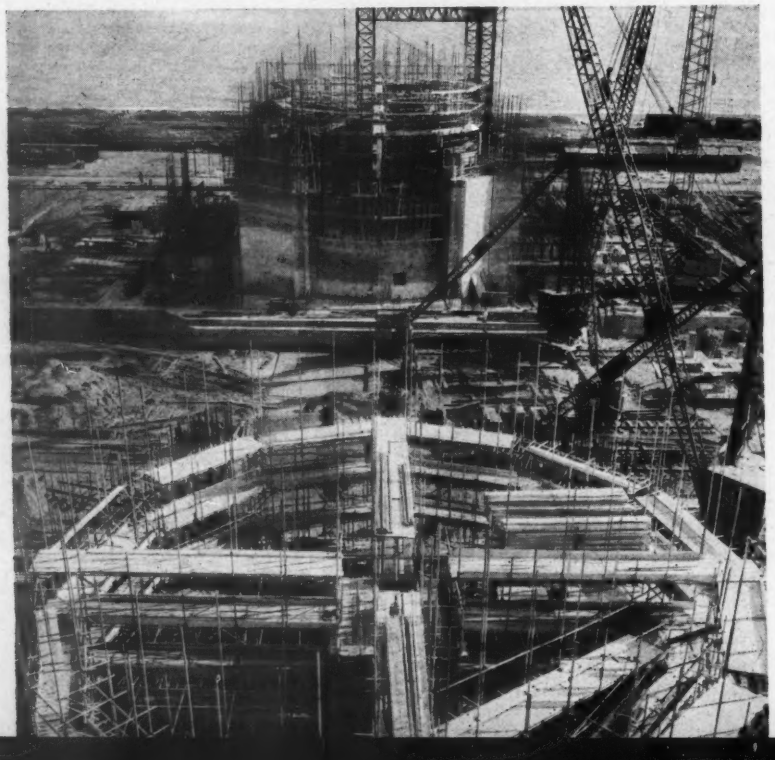
Redeployment of staff at Winfrith is being arranged to permit the present technical strength to be frozen. Some movement from design projects to operations is necessary but no drastic move between establishments is arranged. Administrative staffing is being cut by 10%. The establishment will remain primarily a physics centre but its work more closely related to the Reactor Group's projects.

The Nuclear Power Group have received a questionnaire from the CEGB regarding their tender for Oldbury. They are the only consortium tendering for this station to have done so. It is generally taken as a pointer to the Board's ultimate choice of tender, although of course it is not in any way decisive. TNPG submitted proposals for a concrete pressure vessel system only, while UPC prepared plans for a steel vessel and also a concrete. In the strict order of things UPC were regarded as favourites for Oldbury but the Board has never implied that this was any guarantee. (For comment, see page 502.)

Brazil Seeks Interest in N-station

ORGANIZATIONS throughout the world which are interested in the opportunity of building a 300 MW natural uranium, gas-cooled power station in Brazil have been invited by the Comissaõ Nacional de Energia Nuclear to submit details of their ability to undertake such a project. The CNEN also want to know to what extent the interested parties can develop financial aid for the project. Responses to the invitation are expected to be received before November 27. Evaluation of the replies will lead to invitations to tender for the station being made individually. There is no indication as to how long the evaluation will take or when the invitation to tender will be made. It is intended to build the station in the Guanabara area, on the east coast, near Rio de Janeiro, but to date no specific site has been named. This will, of course, have to be settled before tenders are invited. It is understood that all the British nuclear power construction organizations have received invitations to supply details of their qualifications and that they have all replied.

Progress on the two reactors at Sizewell, shown below, is about six weeks ahead of schedule. The raft for both reactors and all the boiler houses and most of the excavation work for the pump house have been completed. Work started in April.



Australia

Up to the end of June £A16 million had been spent on developing the ARE, Lucas Heights. The main line of research has been directed towards the development of a HTGCR system. At present nearly 850 people are employed there.

An exchange of information with the U.S.A. has been discussed in Washington between Professor Baxter, chairman of the A.AEC, and U.S.AEC officials.

Nothing but a conventional power source was intended for the radio station planned for the north west part of Western Australia, Mr. G. Townley, Minister for Defence, stated in a written parliamentary reply to questions about the station put by Mr. Uren of the House of Representatives. According to earlier reports the station was to be nuclear powered (" World Digest," May, 1961).

Belgium

A grant of $350 000 has been made by the U.S. Government towards the cost of the construction of BR-2. Belgium becomes the 14th country to receive aid under the U.S. " Atoms for Peace " programme initiated in 1958.

Bulgaria

Construction and testing of the country's first reactor—a 2 MW tank type unit supplied by the Soviet Union—have been completed and criticality was expected to be reached soon. The reactor is sited at the Institute of Physics, Sofia.

Canada

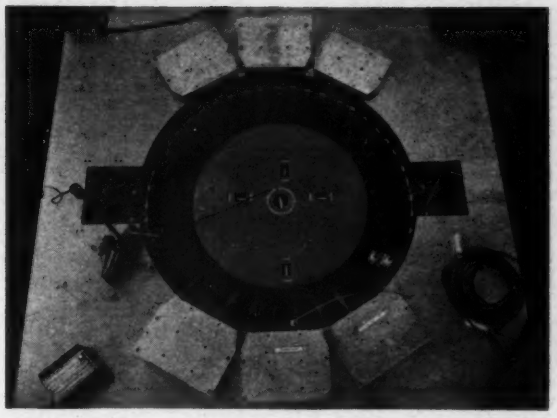
Leak testing of the NPD-2 reactor moderator and coolant sytems has been completed and the filling of the heavy water started. The fuelling machines have been installed and are being filled with heavy water. Fuel loading will start as soon as the reactor and ancillary systems have passed their commissioning tests. Criticality is expected either in December or January.

Fundameutal decisions regarding the future of the organic heavy water project are to be taken in the spring when the present evaluations of Canadian General Electric and AECL are complete.

West Germany

The second GKSS-Euratom contract (" World Digest," September, 1961) has been signed. It covers a contribution by Euratom of DM7 million (about $1·8 million) towards a five year general nuclear marine propulsion research programme. Principal investigations to be made under this programme relate to vibration and shielding. Earlier this year a contract was signed under which Euratom agreed to contribute DM4·48 million towards the GKSS OMR studies (see page 513 of this issue).

Better than a coal-fired station, but not so good as an oil-fired one, was how Dr. H. Mandel, a director of RWE, summed up the calculated economics of a large nuclear power station at Bertoldsheim, near Neuberg. Speaking at the recent meeting of the International Union of Producers and Distributors of Electricity, Baden-Baden, he said that RWE had examined two proposals for such a station. One was for a 300 MW natural uranium, gas-cooled reactor submitted by English Electric, for which the calculated generation price was 3·8 pfennig (0·8d)/kWh and the other for a 240 MW BWR submitted by General Electric in collaboration with AEG for which the calculated generation cost was 4·2 pf (0·9d)/kWh. These calculations were based, said Dr. Mandel, on current prices and conditions for credit and on a 75% utilization factor. He thought that a risk amounting to DM 150-200 million would have to be taken on such a station.



"Argos," the 10kW Argonaut-type reactor built in Spain by the Junta de Energia Nuclear at Moncloa, near Madrid. It recently went critical and is shortly to be moved to the Barcelona School for Industrial Engineers.

Up to October 10 the Kahl reactor had been in operation for 1 700 h providing heat for the production of 14·5 million kWh. It is reported that operations were only once interrupted during that period due to a defect —a faulty turbine component. The reactor is still in operation at only low power, a licence for full power operation not yet having been issued.

An exchange of nuclear scientists with Japan is to take place next spring, according to reports that the president of the J.AEC and the Japanese ambassador to West Germany have been discussing with the Bundes Ministry for Atomic Energy questions of mutual interest relating to the study of nuclear energy for peaceful purposes.

India

The foundation stone to an Institute of Nuclear Medicine and Allied Sciences in Delhi has been laid. A sum of £37 500 has been allocated by the Government towards the construction of the buildings and £30 000 towards the installation of equipment and apparatus.

A five year nuclear information exchange agreement has been signed with Hungary. Information which is obtained from a third country or with the aid of a third country is excluded, as also is information classified as secret.

Israel

The Israeli Ambassador in America recently received on behalf of his country a cheque for $350 000 as a U.S. " Atoms for Peace " grant in aid of the AMF reactor at Nahal Sorek. It was the 13th such grant to be made.

Italy

A reactor of similar purpose to the physical constants testing reactor (PCTR) at Richland, Washington, is being considered for installation at Ispra, it was revealed at the recent IABA symposium on the programming and utilization of research reactors. If of the same type, the reactor would use fully enriched uranium, be graphite moderated and reflected, and uncooled. Power output would be 10-100 W(th). Its purpose—the determination of nuclear parameters for specific reactor designs and for general reactor physics research.

The sharply contested issue of whether privately owned (as against Government controlled) nuclear power stations can be permitted will come up for debate in the Italian Parliament shortly. Even the most enthusiastic supporters of private enterprise seem to regard the question as settled in the negative in which case the Selni 165 MW PWR would have to be abandoned even though site work has begun—unless special provision is made either for an exception to be made in the case of this plant or for Government participation in the project. Main contractors for the reactor are Westinghouse.

Japan

Kyoto University has announced that the Internuclear Company, Chicago, has been awarded a contract for the 1 MW Kansai Research Reactor (KRR) to be installed at Kuatori-cho Sennan gun Osaka Prefecture. Subcontractors for the detailed design fabrication and installation of the reactor, a pool type, will be Hitachi, Nippon Kokon Kaisha and Yamakate Honeywell. This will be the fifth university reactor installation in Japan.

Government approval has been given to a licence and technical assistance agreement made between Mitsubishi Atomic Power Industries and Westinghouse Electric International, of New York, for the manufacture by Mitsubishi of closed cycle water reactors and associated equipment. The agreement covers a 15-year period, during the first five years of which Mitsubishi will pay Westinghouse a sum of $1 million for information. It is understood that Mitsubishi, a consortium of 26 companies of the Mitsubishi group, plan to tender for an enriched uranium reactor to be built for Japco. Government approval has also been given to an information agreement between the United Nuclear Corporation and Sumitomo Atomic Industries relating to enriched fuel manufacture, and a technical assistance agreement between United Chemical and Mitsubishi nuclear ship shielding studies.

Netherlands

The HFR at Petten achieved criticality on November 9. Based on the ORR design it has a maximum power output of 20 MW(th), which is expected to be reached after a period of operation at low power next spring. Before then, however, the reactor vessel is to be replaced with a new one, fabricated, incidentally, in the U.K. by APV. Main contractors for the reactor were Allis-Chalmers. The reactor, the second at Petten, will come under the control of Euratom under the terms of the transference agreement announced earlier this year.

Sweden

The Atomic Energy Board, a five member committee which advises the Government on nuclear questions relating to the appropriations and licensing, has recommended that the Marviken project should be carried out as scheduled for operation in 1967-68. As reported in October there has been some uncertainty to the future of this project due to the State Power Board feeling it was not economically justified. The matter now rests with the Government which will most certainly follow the advice of the AEB.

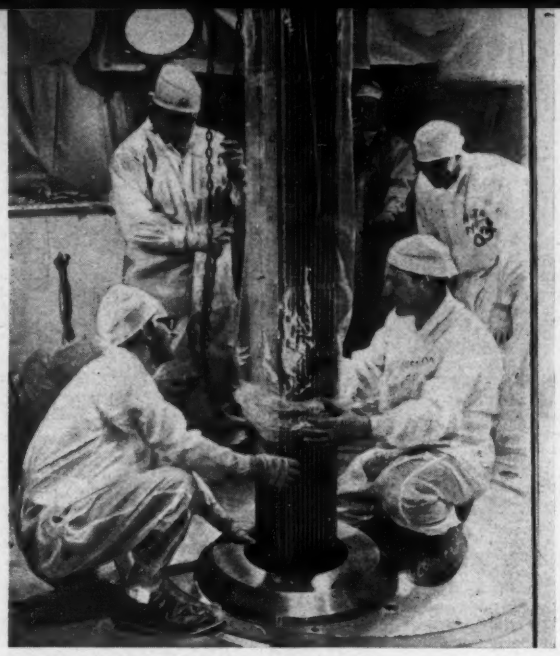
Full power operation of R-2 has been approved by the Atomic Energy Board. It will probably take a month before the 30 MW level is reached, after which, following a week of delivery testing, the high flux research programme will be started. The reactor first went critical in May, 1960, but due to faults in the pressure vessel could not be operated over 1 kW. A new vessel has now been installed.

U.S.A.

Difficulties in finding suitable staff for certain posts have led the AEC to conduct an intensified nation-wide recruiting drive. The posts are related to health and safety work and carry salaries of from $8 000 to $15 000 a year. The basic educational requirement for candidates is a BS degree or equivalent.

A public hearing was being held on November 28 to consider an application by the National Bureau of Standards for a licence to construct a 25 MW(th) CP-5-type reactor at Gaithersburg, Maryland. To be known as the NBSR, the reactor will be used for establishing precision measurement techniques and standards in the reactor field and in areas of basic scientific research. The reactor would be operated initially at 10 MW.

Supervisors of reactor operation would have to pass special examinations under new regulations proposed by the AEC. These would be more exacting than those that are taken by licensed reactor operators. While under current regulations employment of technically qualified supervisors is a condition to the issuance of a reactor operating licence there is no provision for the licensing of the supervisors by the AEC. All that is required is that persons who manipulate the controls of a reactor for start-up, changes in power level, steady state operation and shutdown are licensed. Most supervisors are, in fact, so licensed. It is necessary, however, that supervisors should have a wider knowledge than is required for reactor operation and it is to ensure this that the introduction of a licensed supervisory grade is sought. The AEC are at the same time proposing to stiffen the examinations that have to be taken for an ordinary reactor operator licence.



Loading of the *Savannah* reactor started early November. Our photograph shows a trial run made on November 9. A description of the reactor and fuelling operations appeared in *Nuclear Engineering*, October, 1960.

The need for more effort and drive in carrying out America's nuclear rocket programmes has recently been publicly stressed by both Dr. Glen Seaborg, AEC chairman, and Mr. Melville Price, chairman of the JCAE subcommittee on research, development and radiation. Dr. Seaborg, speaking at the International Symposium on Aerospace Nuclear Propulsion, October 24-26, said that there was a danger of the overall space programme being slowed up due to the lack of development of Snap reactors of sufficiently high power output. It was therefore necessary, he said, that "we concentrate even greater resources with an even greater sense of urgency on development of compact nuclear reactors." He then said that larger energy sources meant the development of a new reactor system and this in turn meant the development of a new technology. It was necessary, he added, for the country to undertake a much larger programme of research and development in materials. Mr. Price, addressing the annual conference of the AIF, November 6-8, complained that all that had been accomplished in the area of high powered Snap development was talk. He blamed inadequate planning and the high turnover of AEC personnel. He said that he felt that the recent reorganization of the AEC would do little in mitigation. One way of ensuring the success of the nuclear rocket programme, he said, was by putting its overall control in the hands of one man.

While there was much to commend the idea of converting ownership of special nuclear materials from the Government to industry, said Dr. Seaborg, at the AIF conference, Nov. 6-8, the dangers involved were recognized. It was intended, he continued, that nuclear power would be an established self-sufficient industry before it was forced to accept the full economic burden and responsibility attached to the ownership of nuclear fuels. The sudden imposition of a requirement for private ownership could well be a serious blow to an industry newly born and still insecure.

The amount of enriched uranium that is made available by the U.S. Government for peaceful purposes in the States and overseas under section 41b of the Atomic Energy Act, 1954, has been increased from 100 000 kg to 165 000 kg. Of this total 100 000 kg will be available to home projects and the rest for distribution to other countries. The new amounts are estimated to cover present commitments and those expected to be made during the next few years under domestic licences and foreign agreements. A new basis for arriving at the total has been used. The previous total of 100 000 kg referred to units of equivalent output of highly enriched uranium from U.S. production plants. Most of the uranium to be made available however will not be highly enriched in U^{235}. Furthermore the domestic licences and foreign agreements are in terms of kg of U^{235} actually contained in the material supplied. For simplicity, therefore, the figure for the new total amount available is expressed in kg of contained U^{235}. As a result the new total does not represent as large a percentage increase as is immediately apparent, the figure of 165 000 kg of contained U^{235} being equivalent to 140 000 kg of U^{235} in highly enriched material.

Following negotiations the AEC have doubled the sum of money they originally proposed to pay Chicago University towards the overhead expenses of Argonne National Laboratory. Even so it is still below the amount claimed by the university. They estimate it costs $1 600 000 a year to run including the library and information facilities and staff. The AEC have agreed to pay $1 200 000 towards this. Some observers see in this apparent change in policy on the part of the AEC an opportunity for the universities to make a profit as do the industrial organizations that operate AEC laboratories.

Permission to carry out "dry zero power experiments" in the 75 MW sodium-graphite reactor at Hallam, Nebraska, is sought by Atomics International, who are building the plant for the Consumers Public Power District, Lincoln. In these experiments the reactor would be loaded with fuel but not with coolant. The purpose of the experiments would be to verify the physics calculations on the core. Permission would not be granted until after the public hearing scheduled for November 30. Another hearing will have to be held before full operation of the reactor will be permitted.

No detectable radioactivity attributable to waste disposal has been revealed by recent surveys conducted on two deep sea dumping sites off the Pacific Coast, report the AEC. The first site is about 48 miles west of the Golden Gate and the other in the Santa Cruz Basin, about 32 miles south west of Port Hueneme, California. The depth of water at both sites is approximately 1 000 fathoms (6 000 ft). Since 1946 some 14 000 c of waste have been dumped into the first area. Dumping at the second site did not start until 1953 and to the date of the survey only 60 c had been disposed of. A third site which is not used for waste disposal was surveyed at the same time as the others to enable background comparisons to be made.

The "pulsing" Triga installed at the Army's Diamond Ordnance Radiation Facility, Washington, was formally dedicated on October 17. To be used for studying the effect of high intensity neutron and gamma radiations on electrical and electronic components, systems and circuits, the reactor—known as a Triga MkF—can be pulsed to a peak power output of 2×10^5 kW(th).

PM-3A, the 1·5 MW PWR built by the Martin Company for installation in the Antarctic, was shipped from Davisville, Rhode Island, on November 1. It was due to arrive at the Naval Air Base at McMurdo Sound on December 15.

ACRS approval has been given to the proposed construction of the 40 MW(e) HTGCR at Peach Bottom. A public hearing to consider the issuance of a construction permit will be held shortly. At the first hearing in March, 1960, it was concluded that there was insufficient evidence on safety.

Another Snap-equipped satellite has been successfully launched into space. The first one, Transit-IV A, which was launched on June 29 (*Nuclear Engineering*, August, 1961, p. 328), is still in orbit and performing satisfactorily. The Snap unit, which provides 2·7 W of power for the satellite's transmitter and navigational instruments, weighs 4·6 lb and is fuelled with about 95 g of Pu^{238}.

Correspondence

Fast Reactor Ceramic

Sir,—Your editorial and Dr. Blake's article (*Nuclear Engineering*, September, 1961) present a perceptive and stimulating analysis of fast reactor prospects and problems. As you point out, there has been a tendency to exaggerate the safety problems of the fast reactor and to neglect some of its compensating advantages. Your example is well taken: the smaller delayed neutron fraction narrows the margin between delayed and prompt criticality, but this is offset by a lower required excess operating reactivity especially for large fast reactors. Another case, less frequently recognized, is the effect of the shorter neutron life-time: while it leads to a faster increase in power, it also renders any negative fuel temperature coefficient extremely prompt and therefore effective in damping accidental ramp reactivity insertions and consequently reduces transient integrated energy generation.

Not to minimize reactor safety considerations, the development of a fuel capable of high burn-up at high rating is indeed the major obstacle to achieving low fuel cycle costs and thus attractive total power generating costs with a fast reactor. The use of voided fuel, as described by Dr. Blake, is a promising approach to attaining such high burn-up and has been receiving attention in the U.S. as applied to both metallic and ceramic fuel.

Some recent results from the Fast Ceramic Reactor Program conducted by GE-APED under U.S.AEC sponsorship may be of interest in this connection. A total of 40 specimens of UO_2–20% PuO_2 fuel were irradiated over a range of burn-ups to 100 000 MWd/t (13% of U+Pu atoms) without a single failure. At the high power ratings (190–590 W/g fuel) to which they were exposed, fission gas release was high (30–70%) and central (axial) voids formed in both pelleted (90–95% dense) and swaged (75% dense) fuel specimens. Fission gas pressure relief was provided by a reservoir within the test fuel element above the active fuel region (1·5 in × 0·15 in dia), thus preventing distortion of the stainless steel cladding (0·016 in thick, operated at ca. 1 000°F).

Following these results, the high rating-high gas release design approach has been taken for oxide fuel, with the reference having a void space above the fuel sized conservatively for 100% release. Follow-up experiments are under way to investigate a number of the questions raised by Dr. Blake; e.g., the response of fuel elements to transient overpower conditions including the possibility of fuel slumping into the void, the consequences of sodium penetration into a defective can, the possibility of segregation of Pu and U in mixed oxide, and the merits of venting fission gas to the coolant to permit low can pressure even at high burn-up.

While emphasizing the case for voided metallic fuel, Dr. Blake has acknowledged certain advantages of ceramic fuel which afford closely comparable economic promise. For example, with the ultimate fast reactor fuel based on Pu as the fissile constituent, oxide fuel has favourable can/coolant compatibility thus avoiding the need for a refractory liner or restriction in coolant outlet temperature required by metallic Pu-bearing fuel. Also, when considering reactor performance as well as fuel performance in comparing fuels, it should be noted that spectrum degradation, as by oxygen or carbon, leads to a negative Doppler coefficient with an oxide or carbide fuelled system thus providing a much desired prompt negative temperature coefficient of reactivity not dependent on mechanical movement. This improvement in safety characteristics may well override the penalty in reduced breeding ratio for ceramic fuel.

A final choice between metallic and ceramic fuel for fast reactors is neither timely nor necessary at this point. What is needed is a continuing vigorous programme of attack on the identifiable remaining problems of both, to assure early capitalizing on the inherent high neutron economy and other advantages of the fast reactor.

GLEN W. WENSCH,
Chief, Liquid Metal Cooled Reactors Branch,
Division of Reactor Development,
U.S. Atomic Energy Commission.

Charcoal Dust

Sir,—With reference to my article in your October issue about a new method to measure the concentration of charcoal dust in air stream by infra-red gas analysis, I would like to point out that it is misleading due to the brevity of its introduction. The method has been developed for test purposes only and no such device is incorporated in the clean-up plant of the Dragon Reactor Experiment, the coolant of which will be extremely pure with an O_2-content of equal to or less than 0·01 v.p.m.

The conclusion in connection with the experimental method derived from the tests has not been included. In the experiment the contribution of CO_2 due to desorption from the charcoal sample had to be assessed in the rather inconvenient way of parallel test runs with the furnace out of operation. As a result of this the suggestion is made to use a "differential" infra-red gas analyser in which, instead of comparing the gas mixture under investigation with a sealed-in reference gas in the calibrated cell, the two gas mixtures are directly compared, measuring the difference in the CO_2 concentration, rather than two absolute values. This differential analyser consists of two identical test cells. Through one of them a sample is drawn, which is taken prior to the furnace. For the other test cell the sample is withdrawn after the furnace. The measured CO_2 concentration difference represents the contribution due to the combustion of the entrained charcoal dust in the air stream of the sample circuit. The article was based on the Dragon Project Report No. 35.

H. F. ENZMANN,
Dragon Project Office,
AEE Winfrith.

Facts Fully Faced

Sir,—I happened to be reading your issue for April 1961 again and came across something which I had not seen before—page 176 in which you make reference to my Faraday Lectures. In the second paragraph on that page you also deal with Professor Blackett's Thomas Hawksley Lecture on Fusion. I think I can assure you that in America, Great Britain and in Russia the difficulties which have developed in the research since 1958 have been well ventilated and spoken of with extreme clarity by practically all the scientists concerned, whether in government or in industry, and I do not think any questions of national prestige have really entered into the matter. I have given a number of lectures since that time, including the Bernard Price in South Africa and the William Menelaus, and I have stated on each occasion the difficulties and the uncertainties ahead of us: I think you will find most lecturers have done the same. I think you need have no anxiety about any absence of frank admission by scientists working in this field.

T. E. ALLIBONE,
Associated Electrical Industries, Ltd.,
Research Laboratory,
Aldermaston, Berks.

Although originally a private communication, Dr. Allibone has given permission for this letter to be published.

Orgel—a European Concept

by J. C. LENY

This article was compiled with the collaboration of MM. Bonnaure, Finzi, Grass, Kind, Laurent, Marchetti, Moranville and Raievski of the Ispra Nuclear Research Centre, and of MM. Chassignet, Gretz, Orlowski and Van der Venne of the Orgel project team, and of M. Denegre, engineer with the Euratom Commission's General Direction for Research and Training.

THE initial programme of research and experiment attached to the Euratom Treaty requires the Commission to carry out work in the field of reactor prototypes. One of the first problems, therefore, which faced the Commission was the choice of a reactor system which could be made a Community project. At the root of the Commission's deliberations was the fact that only with natural uranium reactors could the Community be made independent of outside fuel supplies. By choosing these reactors, the Commission hoped to stimulate industrial projects in the Community and to promote the interests of industry in the export field.

The Orgel system, heavy water moderated, organic cooled (ORGanique Eau Lourde) permits the best use to be made of European industrial potential within the framework of an international distribution of effort.

Heavy water is selected as moderator because of the requirement for a natural uranium fuel. Graphite, which could have been utilized for the same reason, was eliminated to avoid duplication of the studies already going on in Great Britain and France. While heavy water reactor studies are proceeding in many parts of the world to a limited extent, none has yet reached the power reactor stage, although the first prototype, in the course of construction in Canada, is nearing completion.

As regards coolant, heavy water was excluded because of the advanced nature of the Canadian work. CO_2 was also excluded because this concept was born in France, and Euratom avoids duplication of national research. The two coolants left were organic liquid and heavy water mist.

This second approach seemed interesting, but numerous preliminary experiments still have to be made, in particular in the fields of hydro-dynamics, heat transfer and corrosion. These studies are actually being carried out within the aegis of the Euratom/U.S. Agreement, but will not yield tangible results before the end of 1963.

Euratom were not prepared to delay their decision and the Commission chose, for its own reactor study, organic liquid cooling. This concept, moreover, has been considered by the French and Canadians, who, while pursuing their efforts with heavy water, intend making it the primary project at the new Whiteshell research centre.

Studies on the economics of the system so far show that the potentialities compare favourably with those of other heavy water systems under study. In round terms it can be said that even if the cost of the fuel cycle looks like being a little higher than that of a heavy water cooled reactor, it would still be low and insensitive to the unknowns which menace fuel cycle costs of enriched uranium, such as the buy-back price of plutonium and reprocessing costs.

The capital cost, on the contrary, should be lower, because of low operating pressures. With a suitable steam cycle, studies indicate that a net electrical efficiency of 32% can be achieved due to the relatively high coolant outlet temperature. As for running costs they are of the same order as those for a gas cooled reactor. The use of organic coolant reduces the loss of heavy water and the consumption of organic is a very small item.

This means that all in all, the cost per kWh should be similar to D_2O reactors. It is, however, too soon to give an absolute estimation.

Project Organization

The system study is being carried out in two ways; work under contract in the member States' industries and research centres, and studies done at Euratom's communal research centre.

The work under contract fulfills the Commission's requirement under the terms of the Treaty, to promote development in the industries throughout the Community. It is also justified by the fact that the Euratom research centre is still being built up and is not capable of meeting all the needs of the project.

So far as the communal research centres are concerned, the creation of which was foreseen in the Treaty, it was necessary to give them a central project in order to allow them to develop on a sound basis. Only concentration on a common objective enables a group of workers of widely varied backgrounds to become a team which can demonstrate its competence to outsiders. This is why it was decided to concentrate at Ispra, a general purpose establishment, an important fraction of the Orgel work, in particular all the studies being carried out by the Commission itself. At present about 80% of the Ispra work is geared to this. The distribution of the Orgel work in the Community, however, makes it necessary at the moment to co-ordinate the whole from Brussels.

Problems of Organics

The chief problem raised by the Orgel system relates to the organic coolant. At present, the best-known substances are the polyphenyls and, more especially, the terphenyls, consisting of a mixture of the three isomers with fairly high melting points, *viz.* ortho-terphenyl 56°C, meta-terphenyl 87°C, para-terphenyl 213°C.

One of the major problems of an organic coolant is its instability under the action of heat and radiation. At a temperature of 465°C, para-terphenyl will be completely pyrolysed in 17 days. However, there are good reasons for believing that pyrolysis is negligible below 410°C. Under the effect of radiation, terphenyls are decomposed into gases, lighter broken-chain products and heavier polymerization products.

The main reason for using polyphenyls is that their breakdown products are soluble in the initial product and do not lead to the formation of coke, except in special circumstances; moreover, the decomposition products act as radiolysis inhibitors. Against this, they have a detrimental effect on certain physical properties, and in particular on viscosity.

Organics Research

Unfortunately, the mechanism of decomposition is not yet fully understood, so that a considerable chemical programme is needed for Orgel, aimed primarily at elucidating the mechanism degradation. This constitutes basic research and one of the first problems to be tackled is that of the purity of the products requiring comparison of the IR, UV and mass spectra, rather than relying on a melting point or a boiling point test, which gives no accurate indication of small quantities of impurities.

Fundamental research must also be directed to the development of analytical methods; techniques have been perfected for studying pyrolysis and radiolysis but methods of presenting test results seem to vary considerably. For example, it is difficult to compare results obtained by such widely differing methods as measurement of the viscosity of the product, measurement of the volume of gas produced by the reaction or analysis of the heavy product by vacuum distillation.

Basic dosimetric studies are also essential. In order to study the precise chemical effects of radiation, it must be possible to measure quantitatively the radiation energy absorbed by the material. The dosimetry of radiation absorbed by electrons is already fairly well known but the same does not apply to the measurement of pile radiations (n, γ).

Technological studies have been set in hand to elucidate the behaviour of the fluid in the environmental conditions of a

power reactor. This involves the variation of a number of parameters such as fluid speed, impurity and metallic particle content, degradation products, nature and pressure of the blanket atmosphere above the organic liquid, etc., and the adoption of geometries as close as possible to those planned for an Orgel channel.

An in-pile loop has already been in operation for 12 months in the Mélusine reactor at the Grenoble centre. A second is now being built and will come into action at the end of 1961. Both will be used to study polyphenyls with and without radiation up to a temperature of 450°C.

In order to interpret the results obtained with these circuits, methods had to be devised allowing the experimenters to analyse the products at any time.

In the field of gaseous-phase chromatography, tests were performed to find suitable absorbers for the various substances, and silicone elastomers, which appear to have excellent heat stability and good absorption capacity, were finally selected. The three terphenyls have been analysed by this method, to within 2-3%. The tetraphenyls have also been determined qualitatively and analysed quantitatively to within about 2%. Studies are now being directed to high-temperature chromatography, with the main emphasis on the development of very stable stationary phases and longer and wider capillary columns to increase separative power. Research is also in progress in the field of paper and thin-layer chromatography. Stains corresponding to various products have been revealed by ultraviolet light during the tests performed, and it has even been possible to make a few quantitative determinations. A number of hydrocarbons present in the polyphenyls degraded by heat or radiolysis have been isolated in the pure state by fractional distillation and purification.

Two teams of investigators have been working simultaneously on the assessment of water content, using the "Karl Fisher" method. The first used the coulommetric method, producing iodine in the solution by electrolysis while the second adopted titration. Both methods have proved satisfactory and agreement between them has been good; it is now possible to identify about 5 ppm of water in organic coolants. Ideally the techniques need to be adapted for continuous analysis.

The infra-red method was also tried, but results were disappointing. The same applies to methods based on the variation of the dielectric constant with traces of water.

Polyphenyls have been analysed for trace metals, by extraction in the form of ions and detection of the latter in solution. Iron, nickel, copper and manganese are identified fairly well by the flame spectrometer. In the absence of magnesium, a sensitivity to aluminium of 50 ppm is found. These figures will be checked by the activation method.

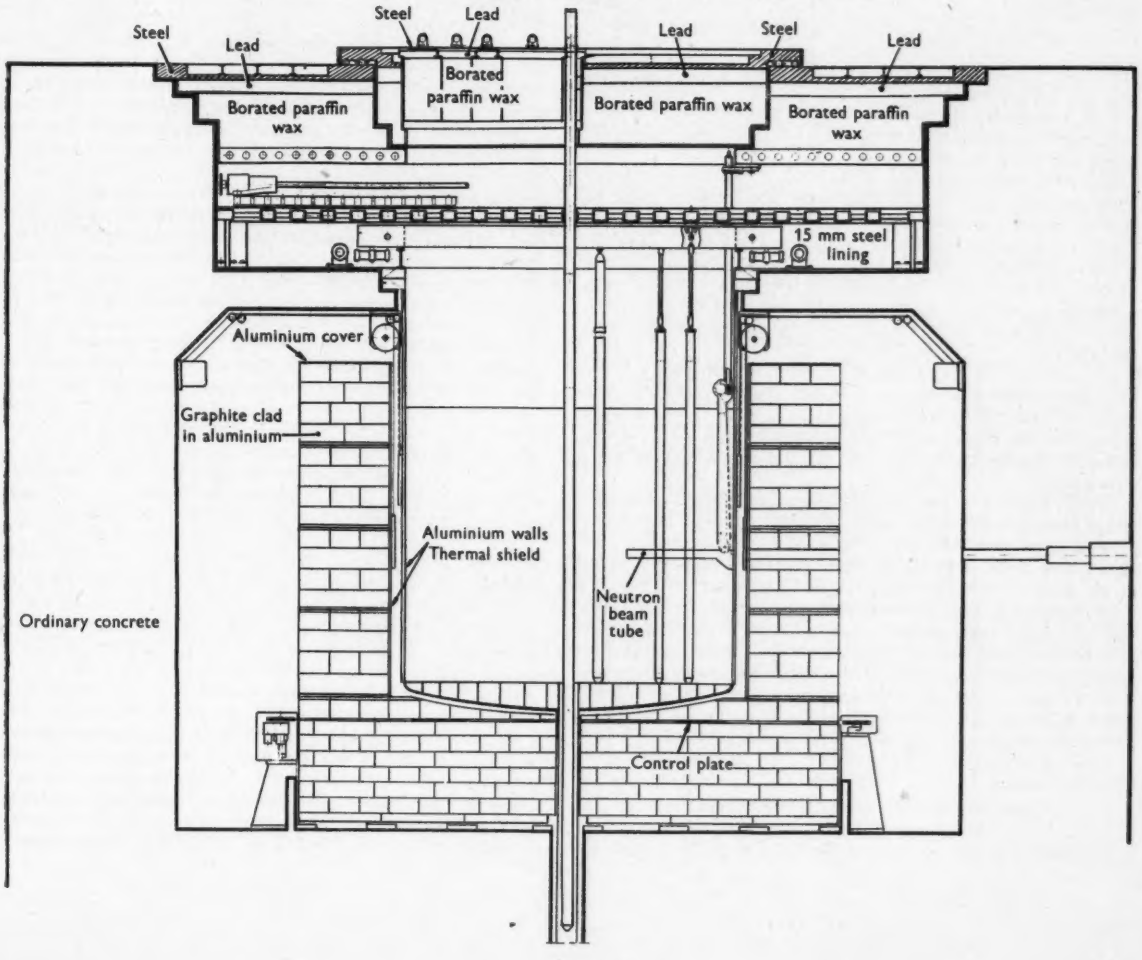
Alternatives to the Polyphenyls

Another feature of the chemistry of Orgel is the search for new organic coolants. Although the rate of coolant decomposition is not as important with Orgel as with other organic reactors, we are extremely interested in improving the operating temperature. We are therefore concentrating on this aspect.

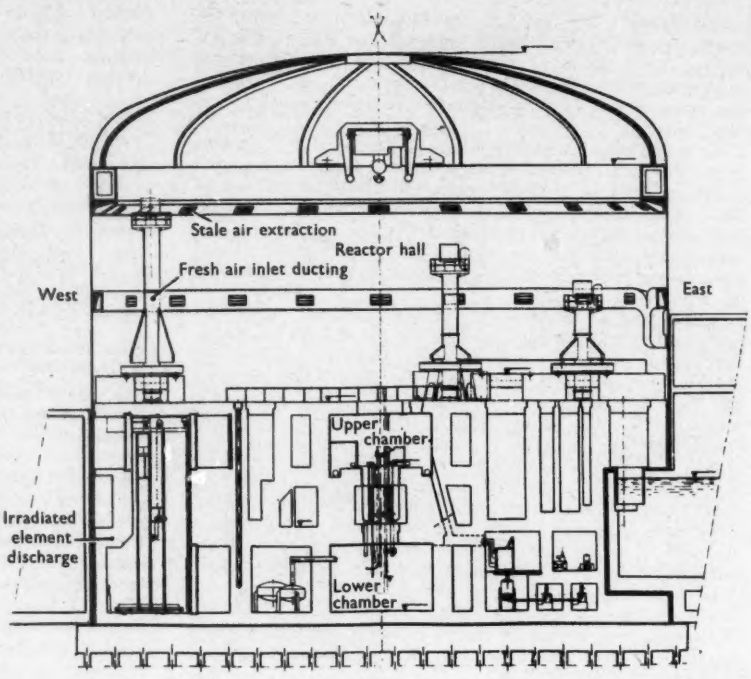
Many laboratories throughout the world have suggested that petroleum refinery products should be used in place of polyphenyls; research along these lines has been carried out in the United States and France. In the latter, several fractions have been examined, with interest focused principally on the high-aromatics, which are about as radiation resistant as the polyphenyls. Heavy power-forming fractions, catalytically-cracked cycle oils, aromatic extracts of lubricating oils and steam-cracked tars have been tested as possible sources of new coolants.

So far, these preliminary determinations have only been carried out on fractions which are of little value for Orgel

Eco, a low power critical assembly intended for heavy water lattice studies.



West/East cross-section through Essor, the special test reactor which is planned as part of the Orgel project.



because of their high vapour pressure. For electrons at temperatures ranging from 120 to 150°C, the polymerization G value varies from 0·3 to 0·5 as compared with 0·2 to 0·3 for terphenyl. The gas G value ranges from 0·04 to 0·15 as against 0·02 for the terphenyls. It would appear that for electron bombardment at low temperature, these petroleum fractions, therefore, decompose at substantially the same rate as the terphenyls whilst their price could be one sixth to one tenth. However, as the cost of renewing the organic liquid represents only a fraction of total price per kWh, these new products are only of interest for Orgel if they can be used to raise temperatures.

Research is currently directed to substitutes for terphenyl which have lower vapour pressures. The thermal stability of those so far studied is not good, but it is too early to form conclusions.

Heat Transfer Research

Returning to the polyphenyls, it must be noted that they are fairly poor heat transport fluids. A series of heat transfer studies have been started to confirm existing theories, establish a basis for estimating heat transfer coefficients under forced convection and investigate possible pyrolytic fouling of surfaces and burn-out under the conditions of the project.

In the case of forced convection, Colburn's relationship seems adequate for simple geometries; we now plan to check it with geometries closer to those of the project. These studies involve the preparation of specimens with a thin heating section, precision made and of material of uniform physical properties, high thermal conductivity and electrical resistance markedly dependent upon temperature.

There are many unknowns in the study of fouling and somewhat unaccountable observations have been made; when an electric element is placed in the organic coolant and heat is applied, the element acquires an adhering, black skin. Furthermore, in OMRE, carbon deposits have been observed forming around metal particles deposited on the fuel element cans. Steel-canned elements seem to be more affected than elements canned with aluminium, or at least steel appears to act as a catalyst.

In addition it is found that after being in the reactor for a time the OMRE coolant has a higher fouling rate than new mixtures and the deposits contained a number of mineral impurities; however, the fouling tendency of the coolant remained the same even after the mineral impurities had been removed.

This problem, which is dealt with at greater length on p. 523, therefore requires detailed study. It calls for the construction of automatic loops operating for as long as possible at very high temperature, first outside, then in pile and, most important of all, basic physico-chemical research is necessary.

As regards the burn-out heat flux, experiments tend to show that it is higher in a mixed, than in a pure coolant; research now in hand will confirm how true this observation is. The programme provides for five loops of varying size.

At the same time, the development of a number of instruments has made it possible to measure the physical constants of the organic products, under working conditions.

Physics Research

A major problem in the case of Orgel is that of neutron physics.

The basic physics phenomena involved in thermal neutron reactors are well known, as is the method of calculating neutron balance. Yet there is no single set of formulæ applicable to all thermal reactors without distinction.

In fact, methods of calculation include simplifications and take only approximate account of all the phenomena. Consequently, the basic formulæ have to be adjusted and supplemented, and the results compared with actual experience, in order to obtain an optimum reactor for the production of power on an economic scale. The special problems arising in Orgel lattices, due to the juxtaposition of the organic liquid and the heavy water, relate primarily to the thermal utilization factor.

The uranium rods and the organic liquid circulating between them are homogenized within the contour of an equivalent zone that surrounds the perimeter of the rod cluster. This leaves an annular section of organic liquid between the imaginary surface and the pressure tube. The extrapolation distance to the surface of the fuel element is then calculated by Amonyal and Benoit's method. A first difficulty is the choice of cross-sections; Westcott's sections are in practice adopted, but the temperature of the neutrons must be known beforehand and even the use of the word temperature is incorrect, because the neutrons do not achieve thermodynamic equilibrium and do not have a Maxwellian distribution. The spectrum of the thermal neutrons depends on the temperature of the heavy water and organic liquid moderators. Because of the temperature difference between the two moderators and because uranium is present, the spectrum is a function of the position in the cell.

This function is calculated according to the method of Selengut; it is assumed that the distribution of the thermal neutrons can be represented as the sum of the two Maxwellian terms corresponding to the respective temperatures of the two moderators and the diffusion theory is then applied to this distribution. In this way, it is possible to define an effective temperature for the neutrons in the homogenized fuel element and in the outside heavy water moderator, and to calculate the corresponding cross-section.

Selengut's theory, as applied by us, gives an accurate estimate of the "heating" of the spectrum by the organic liquid but is not very accurate for the hardening due to absorption in the uranium. We believe that variations in neutron temperature can be calculated reasonably accurately in terms of coolant temperature but that calculations of absolute temperature are

not very reliable. In particular, we have to use more elaborate theories to investigate long-term changes for which exact knowledge of the spectrum is necessary, because of the resonance of Pu at 0.3 eV.

Resonance absorption is a further problem.

The presence of a hydrogenated moderator inside the fuel element leads to increased resonance absorption. To the conception of an equivalent homogeneous element must be added a central hole for which is calculated the proportion of resonance neutrons generated and absorbed in the cluster.

This phenomenon is being studied simultaneously by the Monte-Carlo method. The geometric programme takes into account the real geometry of the cluster; the thickness of the pressure tube, the volume of the organic liquid and the lattice pitch can all be fixed arbitrarily. The programme is, therefore, very complete and can be used to investigate all cases arising in practice.

The factors p, ϵ, f and even k can be calculated under the physics programme. The statistical fluctuations inherent in the method can be substantially reduced by a special method based on the principle of statistical weighting and the game of Russian roulette. A perturbation method has been devised to obtain the temperature effect. When this programme has been tested on the IBM 7090 at the Ispra Centre, we shall be able to make exact calculations, checking the details of the formula.

As regards long-term changes, we have to calculate how the burn-up of the fuel elements is affected by uncertainties in the cross-sections of the Pu isotopes. It has been found that uncertainties regarding cross-sections are unimportant in the case of Pu^{240} and Pu^{241} as compared with Pu^{239}. A 1% error with the latter causes a 0·5% error on reactivity and a 12% error on burn-up, for an initial reactivity of 2%.

The first experimental studies were made in the reactor Aquilon with metal plate-elements; experiments with UO_2 are now in progress. In both cases, the fuel is surrounded by an organic liquid at normal temperature. These studies will be continued with the Orgel Critical Experiment (l'Expérience Critique Orgel, ECO) to be installed at the Ispra Centre.

ECO

Eco is a low-power critical assembly, moderated with heavy water, a large volume of which (25 ton) is available. This will allow the accurate measurement of small buckling factors (1 to 1·5 m^{-2}) and also on unreflected lattices. The replacement method will be used, with a reference lattice consisting of clusters of 19 uranium metal rods, surrounded by organic liquid in an aluminium tube. The reference lattice can be modified by putting the rods in clusters of 12 or 22.

One of the original features of the Eco is that it will be possible to heat the substitute lattice, which will be made up of independent cells, suspended in place of the normal elements of the reference lattice. Pitch is altered by a device which may possibly be made to oscillate around a fixed value. If so, it will be possible to measure not only buckling at a given pitch but also the tangent at that point, thus considerably increasing accuracy.

The Eco reactor will have a mechanism for oscillating the central element. With this device it will be possible both to observe more accurately the effect of replacing a rod and to study long-term changes by replacing part of the centre rod, either by a section of synthetic rod simulating the state of the fuel after irradiation, or by a section of irradiated rod.

The technical specifications for Eco were drawn up in February, 1961, and tenders for a detailed preliminary scheme were called for in April, 1961. A research group was selected from among the tenderers and asked to prepare a final scheme. Construction can, therefore, begin in the near future, so that criticality will be achieved in January, 1963.

Fuel Element Development

The use of an organic-liquid coolant theoretically allows a wide choice of materials for the fuel element.

We have, therefore, considered uranium metal, uranium oxide and uranium carbide as possible fuels. The conditions of the project rule out unalloyed uranium metal; neutron and thermal considerations suggest a divided fuel (concentric tubes or clusters, with the latter by far the more realistic); and second, the strict neutron limitations on the factor coolant volume/fuel volume (which must be very small) call for very narrow clearances (about 1 mm) between the rods forming the clusters. This means that only a very small amount of swelling under irradiation can be allowed.

If uranium is to be used, attention must, therefore, be concentrated on alloys which are resistant to irradiation deformation, without altering the neutron balance. These requirements it is thought, limit the field at present to uranium-molybdenum alloys, containing only a small percentage of molybdenum.

The French CEA is conducting major research into U-Mo alloys and Euratom has no plans of its own for production studies. We shall, however, have to investigate the following points in connection with this material:

(1) behaviour under irradiation in conditions resembling those of Orgel as closely as possible;
(2) canning.

The first canning material to come to mind is magnesium which has low absorption and is perfectly compatible with uranium at the temperatures planned; on the other hand, it corrodes very badly as soon as the water content of the organic liquid exceeds a few tens of ppm. Before reaching any conclusion on this point, it will, therefore, be necessary to check the corrosion performance of magnesium and its commercial alloys in the organic liquid.

The next material is aluminium which has good corrosion resistance in organic liquids, but is incompatible with uranium at the temperatures involved. We are, therefore, studying possible diffusion barriers between these two elements.

Finally, canning with thin stainless steel may be possible and this point is discussed later.

Information concerning uranium oxide is available from many sources, both within and outside Euratom. Consequently, no research has been undertaken on this subject for Orgel.

The major effort has been concentrated on uranium carbide and, from the first data published, there are grounds for hoping that its behaviour after irradiation may be comparable with that of the oxide, while its greater uranium density gives it an apparent advantage over the oxide from the neutron standpoint. Its good thermal conductivity as compared with the oxide and the absence of any phase change suggest that centre rod temperature is no limitation.

Our programme therefore comprises:

(1) Development of production, by arc melting of UO_2 and C, followed by precision casting of rods.
(2) Development of production of U + C powders, by extrusion or compaction.
(3) Development of production of porous UC pellets or small bars by the reaction of UO_2 + C in the solid phase.

Research also covers the following points:

(a) Precision casting by electronic bombardment from expendable electrodes manufactured by powder metallurgy.
(b) The impregnation of porous carbide (cermets U — UC or others).
(c) The measurement of physical and mechanical properties.

As intrinsic strength cannot be expected from a ceramic fuel, the mechanical properties of the canning material are of major importance.

Attention has been concentrated principally on sintered aluminium powder, the programme for which comprises:

(a) Determination of the properties of two types of sintered aluminium (SAP and Frittoxal).
(b) Production development of both types.
(c) Studies of welding by different methods and of brazing.
(d) Studies of corrosion.

This programme is supplemented by a series of standard measurements non-destructive tests and tests under irradiation (in-pile creep).

Work on finished fuel elements includes a study of UC densification by vibration in SAP tubes and all activities connected with the assembly of prototype clusters, thermal cycling, temperature drop at fuel-can interface, etc.

Some results are already available, relating principally to the U — Al diffusion barrier in the case of uranium metal. Studies on nickel have confirmed that this barrier is ineffective at

temperatures above 375°C, unless thicknesses are increased beyond the acceptable maximum.

In the case of vanadium and niobium, the problem is to devise a surface treatment of the uranium which will allow an adhering, non-porous deposit to be applied, either by electrolytic deposition or by vacuum metallization.

Studies of the production of uranium carbide by arc melting are progressing; methods of crushing to prepare the UC powder have been perfected, but the problems of checking composition, homogeneity and carbon content are still far from being resolved. Densities equal to 70% of theoretical density are now obtained by vibration densification, and this figure is raised to 95% by subsequent compaction. Pellets with a 98% density are obtained by sintering under compression.

In the case of SAP, production studies have yielded smooth drawn tubes containing 4% alumina, selected for cans with the following tolerances: external diameter 14·7 mm ± 0·05, thickness 8/10 mm ± 0·04. These tubes, produced in a vacuum, are free from blisters when heated to 600°C. A fin ratio of 3 has been obtained with finned tubes; semi-industrial production now has to be developed. All mechanical properties have been determined.

In welding tests with SAP, we have so far succeeded in welding SAP containing 4-7% alumina by electron bombardment; the welding of grades containing 10 to 14% alumina would appear to be extremely difficult. Careful degasification is necessary before the operation, to avoid blistering of the product. Sheets of SAP 0·5 mm thick have been spot-welded ultrasonically. Results are not easy to reproduce however, because it is difficult to concentrate the vibrations on the pieces to be welded.

Another very promising technique is the "welding" of the plug by inside rolling. The welds so obtained are helium-tight and resist considerable pressures (270 kg/cm²). Efforts are now being concentrated on the development of plugs to which the rods can easily be attached.

Helium-tight welds are also obtained by "flash welding" but this is a crude method which we are trying to improve.

In the matter of irradiation, our programme is concerned mainly with an SAP rig; sample tubes are heated to 450°C and stressed by CO_2 pressure, and irradiated for 1 000 hours.

We are also preparing a fuel-rod irradiation loop, which will be installed in the materials testing reactor at Mol, BR–2. SAP-canned carbide rods produced in Europe are also to be irradiated in the Canadian NRX reactor.

We are also studying the possibility of irradiating carbide capsules to study their properties.

Power Reactor Outline Design

Before giving further details of the research programme, it may be useful to summarize the characteristics of a possible 300 MW(e) reactor. This would comprise a cylindrical, vertical-axis, steel vessel, containing cold heavy water (60 to 80°C), used as moderator and reflector, slightly pressurized by helium. A cluster of vertical calandria tubes of aluminium would be sealed between the two vessel ends, physically separating the D_2O from the other media. An annular space between calandria tube and co-axial channel tube would provide thermal insulation between the cold moderator and the hot coolant. According to the insulator chosen, coolant pressure would be carried either by the calandria tube or by the channel tube. The fuel element would be of uranium carbide. In any event the quantity of organic coolant in the cluster must be kept down to the minimum needed for heat transfer. It may, therefore, be necessary to use fillers which will probably form an integral part of the fuel cluster, where they will play a mechanical role.

The average ratio between organic liquid surface and fuel surface in a channel is expected to be 0.5. The clusters so far considered consist of 4, 7, 19 or 22 rods.

Pressure Tube Design

Pressure-tube reactors raise difficult technological problems, principally concerned with the thermal isolation of coolant and moderator, junctions between channels and outside circuits, fretting inside the channels as a result of vibration and differential heat expansion and the thermomechanical stability of the fuel elements. The equally complex problems of charging and discharging with the reactor running are linked with the use of natural uranium with its narrow margin of reactivity.

The thermal insulation of the pressure tubes involves a compromise between neutron economy and heat losses from the coolant to the moderator. The tube thickness depends on the high temperature strength of the material used and the uncertainties still remaining regarding the properties of SAP under operational conditions incline us to favour a cold pressure tube of aluminium.

A solid thermal insulation would then be satisfactory but the difficulty is to find one with good performance under radiation, low neutron capture and low thermal conductivity (high porosity). The first to come to mind are the refractory oxides (aluminium oxide, silica) with minimum porosity of 60-70%. At the moment their technology is not sufficiently advanced, so studies have been put in hand.

A number of experimental models, one of which will be used to study the transmission of pressures, are now under construction at Ispra.

If SAP can be used as a hot pressure tube, insulation with stagnant or slightly circulating gas would appear best from the thermal standpoint. An experimental assembly is now being set up at Ispra. The solutions developed will be tested in a big 40 m³/h, out-of-pile loop, comprising a full-size Orgel channel. With this circuit, which will come into use in mid-1962, it will be possible to apply thermal shocks of 100°C in a few seconds, at a standing temperature of 420°C, pressures up to 40 atm and coolant speeds up to 10 m/s.

In the matter of junctions, the problem is to join SAP to mild steel under channel conditions. The joint must be completely leakproof and easily replaceable. Sandwich and expanded joints seem to be giving good results at present. A test-bench is now being set up for pressure cycling up to 300 c/min.

Other problems to be studied are friction and abrasion arising in the channel through vibrations caused by the pump, thermal expansion and coolant circulation.

ESSOR

Although irradiation work is planned we do not regard this as a sufficient basis for studying a reactor system. We have, therefore, under consideration a special test reactor for Orgel, the main feature of which will be extreme flexibility. It will enable us to gain experience of the heavy water and the organic liquid, while at the same time avoiding the necessity of deciding too early on the solution to any particular problem.

In this special test reactor, a driver zone will serve as the neutron source; the elements will be of a well-tried type (MTR–BR–2) cooled and moderated with heavy water.

Studies have been carried out to interpret the observations made with a test reactor of this kind. Their particular purpose is to evaluate the minimum number of experimental channels from which significant observations can be obtained. A figure of 8, plus four separate channels forming a once-through circuit, has been fixed.

European industry was asked to submit a preliminary scheme for this reactor named Essor (ESSai ORgel). Several national research agencies were consulted and agreed to the Euratom Commission's suggestion that they should combine to set up "European" research agencies. One of these has been asked to prepare detailed preliminary plans for July, 1962, following which the construction of the reactor could be complete in three years.

Finally, it may be noted that research work on Orgel is spread throughout the Community. The technical studies carried out by Euratom itself are concentrated at the Ispra Centre where Orgel is the primary concern of several major departments; overall co-ordination is dealt with by Euratom headquarters in Brussels.

Industrial firms working on research contracts collaborate closely with the Ispra departments, with a full exchange of ideas and minimum dispersal of activities. The Orgel budget, amounting to about $7½ million in 1961, is divided almost equally between work at the Ispra Centre and research by industrial firms in the Community.

OMR Projects in Germany

EUROPE'S first organic moderated power reactor plant could possibly be the 150 MW station planned for Mosbach, about 45 miles north-east of Karlsruhe, Germany. Design studies are due to be completed by March of next year and if they are approved aid for the construction and operation of the plant will be sought under the terms of the joint U.S.-Euratom power reactor programme. To qualify for this the station will have to be completed for operation by 1965.

The Germans also have serious plans for building an OMR marine propulsion unit. Design work is now under way and, as in the case of the land-based plant, a decision as to whether to build or not is to be made during early 1962.

Both projects are based on the OMR concept developed by Atomics International, who in fact are carrying out the design studies on the 150 MW plant in conjunction with Brown, Boveri and Cie., who are responsible for the conventional parts of the plant. The ship design is being undertaken by Interatom, the Bensberg, Cologne, company jointly owned by AI and Demag, of Duisburg. Interatom are also carrying out a study on a 15 MW land-based OMR to provide a basis for a comparative economic assessment of large and small sized OMR plants.

Ever since they were originally announced the two major projects have been dogged with setbacks and postponements, mostly due to financial reasons, and even now it is not a certainty that they will be continued. In the case of the marine project, however, the directors of Gessellschaft für Kernenergie Verwertung in Schiffbau und Schiffahrt mbH (GKSS) of Hamburg, for whom the ship design is being undertaken, have announced that economic factors will only be of secondary importance in their final decision. The final decision will rest on technical and safety considerations.

The Mosbach station certainly has more chance of becoming a reality than the projected plant put forward for consideration under the U.S.-Euratom programme two years ago.

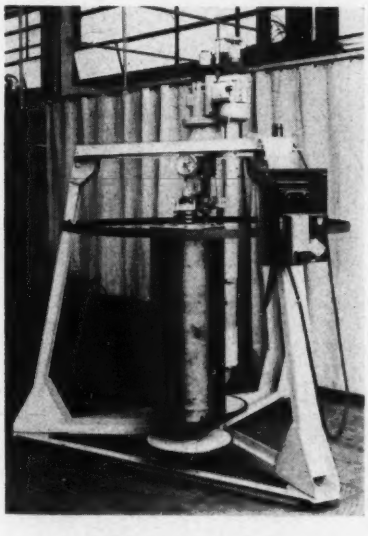
Plans for an OMR power plant were first discussed at the end of 1957 and in February of the following year Atomics International submitted to Arbeitgemeinschaft Baden-Württemberg zum Studium der Errichtung eines Kernkraftwerkes (AKS), a group made up of six utility companies centred in Stuttgart, a proposal for a 100 MW OMR plant. The submission was made through the then newly formed Interatom. AKS decided it would rather support a 150 MW plant and six months later AI submitted a bid proposal for this size plant. The following April proposals for aid under the U.S.-Euratom programme were invited and the AKS OMR was tentatively submitted for consideration. It was announced that the Bundes Ministry of Atomic Energy had approved financial support to the tune of DM 10 million to underwrite the cost differences between a coal-fired and nuclear power station of the same output. Later it was found that this cover would be inadequate, and as the Ministry was reluctant to increase its support the AKS withdrew their submission.

Model of the OMSR on which Interatom is working for GKSS.

In later discussions it was made clear that provided the project could be ready for operation by 1965 there would still be a chance of it benefiting under the terms of the U.S.-Euratom programme. In early May, 1960, AKS decided to award a design contract for a 150 MW OMR plant to AI and Brown Boveri, and at the same time obtain a bid proposal from Interatom on a Piqua type small nuclear power plant. Negotiations continued into 1961—the contract for the large plant being signed in March and for the small plant in May.

In the meantime, AKS, which had only limited powers, was disbanded and a new group, Kernkraftwerk Baden-Württemberg Planungsgesellschaft (KBWP) formed in its place. Following the signing of the contracts the Bundes Ministry announced it had allocated DM 1·775 million towards the projects.

At the time of writing the preliminary designs were completed and work was under way on details. Both designs should be completed by March of next year.



Rig for rotating ship reactor components as used by GKSS at Hamburg.

The Ship

Preparations for Germany entering the marine nuclear propulsion field were started in 1956 when GKSS was formed with financial support coming from West Germany's four coastal provinces and the central government. It was not until three years later however that a firm decision was made for Interatom to undertake a theoretical study and conceptual design of an OMR plant for the group. In 1960 a further contract was signed obliging Interatom to produce a design by the end of 1961 or beginning of 1962 from which GKSS could actually start construction work.

During 1960 moves were made to obtain Euratom support for GKSS but this only came after the Bundes Ministry increased its own share in the group from a third to 51%

Early in 1961 it was announced that Euratom agreed to contribute up to $1 million towards the OMR studies, representing about 40% of the predicted total cost. On October 31 Euratom signed another contract with GKSS, this time for more general studies in marine propulsion work. It is worth about $1·8 million and covers a five year period.

In September Kieler Howaldtswerke, of Kiel, were selected as the contractor for construction of the hull of the 15-16 000 ton freighter in which the OMR would be installed. Seven proposals had been submitted and eight months were spent in evaluating them. The hull is being so designed that at a later date the first reactor unit can be replaced.

A preliminary safeguards report on the OMR system was submitted to various authorities in July, 1961, and received provisional approval. It is hoped to start construction of the reactor and vessel next year.

Two U.S. Projects . . .

The 50 MW OMR . . .

LITTLE progress has been made with the AEC plans for the construction of a 50 MW(e) OMR power plant in conjunction with either a public or municipal utility company. Invitations for expression of interest in such an enterprise were issued at the end of 1959, but to date, even after a second round of invitations, only one utility has decided it might be a worth-while project to join. The Grand River Dam Authority, of Oklahoma, made their interest known in July of this year but since then nothing further has been heard. The general feeling is that the AEC will build and operate the plant on their own.

The first invitation for expression of interest in a 50 MW OMR plant was made with a request for ideas about a BWR plant. The latter led to negotiations over the possibility of an improved BWR being built for Los Angeles and Pasadena, which was later dropped. Nothing, however, came out of the OMR invitation.

A year later the AEC repeated the OMR invitation. This time a response came from nine companies and groups. When the Commission asked in April, 1961, for more definite proposals four of the utilities still seemed interested: they were the Grand River Dam Authority; Dairyland Power Co-operative, of La Crosse, Wisconsin; the Burlington (Vermont) municipal utility system; and the Plains and Electric Generation and Transmission Co-operative, of Albuquerque, New Mexico. Only the GRDA, however, expressed continued interest. Dairyland said that they had become interested in a BWR project while the Albuquerque utility just dropped the idea.

Burlington informed the AEC that it had arranged to obtain necessary power from other sources, with the result that it would not be able to operate the proposed OMR plant as a base load station. This had been an essential point to the AEC's invitation. They also pointed out certain technical uncertainties which they said would have to be resolved before the project could be undertaken. In addition, Burlington criticized aspects of the proposed contractural arrangements, saying that they objected to the lack of guarantee by the AEC of full capacity operations at an 80% load factor.

. . . and the EOCR

CONSTRUCTION of the 40 MW(th) experimental organic cooled reactor (EOCR) at Idaho Falls is about 75% complete and criticality is expected to be reached some time late 1962. Designed by Phillips Petroleum in collaboration with Atomics International and to be operated for the AEC by Phillips, this reactor is being built to provide supplementary data and operating experience on the OMR system and to help in the development of improvements for future organic reactors. It will be equipped with five in-pile loops for testing new coolants and fuel elements and will provide an opportunity for the investigation of the use of both graphite and heavy water as moderators in organic reactors.

The range of work to be carried by the EOCR is summarized as follows:—

1. Develop new fuel elements for organic cooled power reactors.

2. Develop new or modified coolant materials for use in organic cooled reactors moderated by D_2O, graphite or organics.

3. Develop improved methods of fuel and moderator separation for organic cooled, solid moderated reactors.

4. Conduct heat transfer tests with fuel elements cooled by organics.

5. Conduct physics tests with different core configurations.

6. Conduct tests with core arrangements and fuel elements proposed for power reactors at their design power densities.

7. Test auxiliary processing equipment.

Summary of Data for the EOCR

Power	40 MW
Fuel	Sintered UO_2, APM clad
Positions in core	37
Positions in reflector	20
Fuel elements	20
Loop positions:	
6·5 in o.d.	2
2·5 in o.d.	3
Capsule positions	25
Rabbit facilities	2
Lattice pitch (square)	5·75 in
Fuel plates/element	46
Element length	13 ft
Element cross section	4 in²
Plate thickness	0·03 in
Core alloy thickness	0·02 in
Cladding thickness	0·005 in
Coolant channel thickness	0·125–0·255 in
Nominal spacing between elements	1·75 in.
U^{235} element	16 kg
Control rods	12
Control rod type	Fuel follower
Clad poison material	B^{10}–SS or B_4C
Control rod worth	31% Δkeff
Active core volume	615 l
Active core length	35·5 in
Total U^{235}	52 kg
Initial core effective reactivity	1·16
Coolant	Santowax R or OMP
Inlet temperature	500°F (40 MW)
	700°F (20 MW)
Outlet temperature	525°F (40 MW)
	715°F (20 MW)
Max. coolant velocity in fuel	37·5 ft/s
Min. coolant velocity in fuel	9·0 ft/s
Core pressure drop	40 psi
Average heat flux	144 000 Btu/ft²h
Max. heat flux	660 000 Btu/ft²h
Max. fuel element surface temperature	850°F
Burn-out heat flux	2 140 000 Btu/ft²h
Height of reactor vessel	18 ft 9 in
Inside diameter	7 ft
Design pressure	300 psi
Design temperature	850°F
Fabrication material	347 SS
Wall thickness	1·25 in
No. of pumps	1
Coolant flow	25 000 gal/min

India's Contribution

Studies for a 20 MW(e) organic cooled heavy water moderated reactor plant have been made by the Department of Atomic Energy, India, and in the department's 1960-61 report it was stated that "a project for the construction" of this reactor was "expected to be started shortly."

At the present moment, detailed cost estimates are being prepared and a limited experimental programme got under way. A major piece of equipment to be ready shortly will be the first 400 kW loop designed initially for out-of-pile testing but for insertion at a later date in the Canada-India reactor.

In spite of the close similarity between this study and the original OCDRE study in Canada, and the close liaison between the two countries through the Trombay MTR there is no formal collaboration on organic projects. The system was also largely ignored at the top level symposium in Bombay last January (proceedings of which have now been published) but this may merely be a comment on the project's newness.

PIQUA NUCLEAR POWER FACILITY

1. Status Report

by **E. F. WEISNER**

(Formerly Project Engineer, Piqua; Presently AI Project Engineer for KBWP)

AS the year 1961 draws to a close, so has the construction phase of the Piqua Nuclear Power Facility. Designed and built by Atomics International for the United States Atomic Energy Commission, it is part of the AEC's Power Demonstration Reactor Programme. The project is now in the pre-operational testing phase—an extensive and complete programme to test every subsystem of the plant both independently and in conjunction with each other. These tests are in addition to the component tests already performed by the construction contractor and the equipment suppliers. They will simulate as nearly as possible conditions expected when the plant begins actual power operation early next year.

The broad engineering design of the reactor plant was described in an article published in the February, 1960, issue of *Nuclear Engineering* and is expanded in the following pages.

The reactor vessel, fabricated in California, was delivered by rail to the site and installed into position in the cavity liner in March, 1961. This vessel weighs approximately 40 tons but presented no unusual or particularly difficult handling problems. The internals of the vessel (grid plates, thermal shields, and outlet thermocouple assemblies) were installed in October, after the completion of the hydrostatic testing of the entire primary coolant system. The steam boiler, which weighs slightly in excess of 40 tons was also installed in March, 1961, followed rapidly by the remaining major items of process equipment.

The fuel elements were manufactured by Atomics International in its Canoga Park facility and are presently in storage there.

After completion of the testing phases, the operation of the reactor power plant will be turned over to the City of Piqua, who will operate the plant for the AEC. The operating crews, both from AI and City of Piqua, have undergone an extensive training programme which began in July, 1960. All systems of the plant were studied in detail including all aspects of the testing programme and operating manual. The operator-trainees also spent several weeks at the Organic Moderated Reactor Experiment studying the operational aspects of the world's first operating organic power reactor. The operating crews of both organizations have spent the past several months in Piqua observing the final phases of construction to gain familiarity with the plant.

The final safeguards report was submitted to the AEC in April, 1961, and was approved by the Advisory Committee on Reactor Safeguards in May. A public hearing must still be held and licensing examination of individual operators have yet to be completed before loading of fuel may commence.

Early in 1962 the turbines of the Piqua municipal power plant should commence receiving steam from the reactor. This steam will be supplied to the existing steam headers of the regular coal fired boilers. Then 11·4 megawatts of electrical output will be due to the steam produced by nuclear fission in the Piqua Nuclear Power Facility, thus marking the beginning of electric power production by organic moderated reactors.

2. General Description of the Piqua Reactor

PNPF is a 45·5 MW(th) reactor located on the east bank of the Miami River, near the city of Piqua, Ohio, and will be operated by the City of Piqua Municipal Power Commission, supplying superheated steam to an existing power station on the other side of the river. The general arrangement of the reactor plant is shown in the pull-out drawing facing page 522.

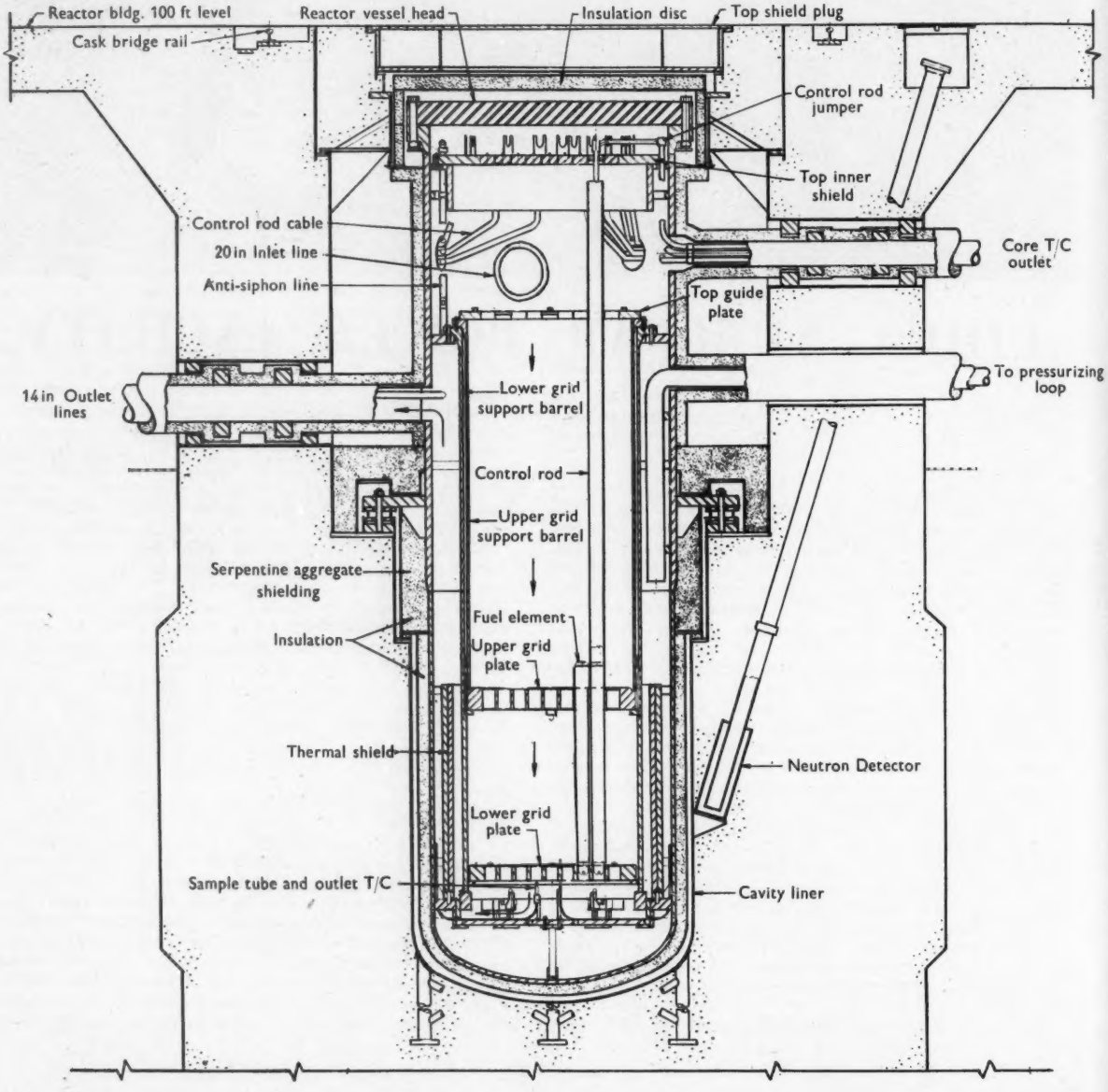
The plant consists of two main units, a reactor building and an auxiliary building. The first, containing the reactor, main heat transfer loop, with its associated degasification, pressurizing, and decay heat removal systems, is built as a domed containment shell with steel walls and a concrete lining. It has been designed for an internal pressure of 5 psig, with a maximum leakage of 0·2% per day for each psi of differential pressure between the inside and atmosphere; it is provided with air-locks. The second building, of conventional insulated steel-panel construction, houses all auxiliary process systems not requiring containment such as ventilating fans and filters, coolant purification and make-up, waste gas, organic and aqueous waste disposal systems, the control room, etc. This building is provided with shield walls where necessary to control radiation levels.

Core

The core of the reactor consists of 85 fuel elements arranged in a triangular lattice to form an approximate cylinder as shown in Fig. 4. (At start-up, 15 elements will be replaced by dummies to limit initial reactivity with fresh fuel.) Core characteristics are given on the data sheet incorporated with the pull-out.

Each fuel element basically consists of two concentric cylinders of enriched uranium-molybdenum alloy with a small amount of aluminium added as a stabilizing element. These cylinders are each clad with finned aluminium, metallurgically bonded to the fuel using an intermediate diffusion barrier of nickel 0·001 in thick. Both outer and inner tubes are made up in four sections, the aluminium finning being suitably machined

Fig. 1.—Vertical section of PNPF reactor.



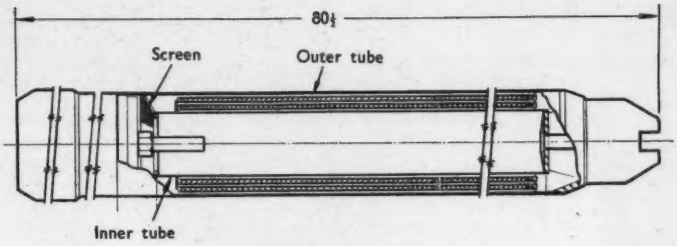


Fig. 2.—Simplified section of fuel element.

Fig. 3.—View of part of fuel element.

so that the sections nest together. The finning has a longitudinal twist, outer and inner tubes being twisted opposite-handed; this not only allows the inner tube to nest inside the outer, with touching fins assuring concentricity, it also relieves any tendency for the element to be rotated by the coolant flow.

The concentric finned fuel tubes are enclosed between inner and outer stainless steel tubes fastened to the upper and lower end-pieces which fit into the upper and lower core plates when the element is in the reactor; the weight of the element is taken from the top core plate.

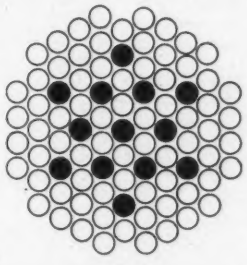


Fig. 4.—Diagram of core lattice. (Solid circles show location of control rods.)

The main coolant flow is in a downwards direction through the annulus between the two stainless steel tubes. Each top piece (except those intended to house control rods) is provided with an adjustable inlet orifice to regulate coolant flow so as to permit equalization of operating temperatures throughout the core.

Any particulate matter in the coolant is prevented from entering the annular space, and clogging the finning, by a stainless steel screen at the top end; this is set at an angle between the outer and inner tubes so that its projected area is larger than the cross-section of the annulus.

Control

There are 13 control rods located inside selected fuel elements. Each poison element consists of boron carbide-filled stainless steel tubes brazed together to form two concentric rings of tubes. The amount of reactivity controlled and scram times, etc., are given on the pull-out.

Magnetic jacks are provided for control rod operation, giving raising and lowering in small discrete steps by energizing stationary grip, lift, hold, and pull-down coils in the proper sequence, while sensing coils determine the position of the rods for remote indication purposes. Scramming takes place automatically if the operating coils are de-energized; the rods drop under gravity and the shock is absorbed by Bellville springs; about 2-3 in of bounce occurs but the amount of shutdown reactivity momentarily lost by this bounce is negligible.

The entire rod and mechanism is contained within the reactor vessel, the mechanism and coils being hermetically sealed in stainless steel cans.

Pressure Vessel

The reactor vessel is of SA 212 mild steel and is 7 ft 8 in inside diameter and 27 ft 3½ in high. The lower portion of the shell and the domed bottom are 1⅛ in thick; the upper portion of the shell is 2½ in thick. The unit is designed as an unfired pressure vessel for 300 psi at 750°F; the top plate is of mild steel, flat, and 9 in thick, bolted to a flange around the vessel shell and fitted with a copper gasket to provide sealing.

As will be seen from the pull-out drawing and Fig. 1, the vessel is installed below ground level and is supported by means of brackets some 16 ft below floor level.

The core, which is located at the lower end of the vessel, is actually supported from a position only about one-quarter of the vessel's length from the top, where a circular ledge is provided. From this hang two concentric steel barrels, the outer one supporting the lower grid plate and the inner one supporting the upper. At the point of support of the two barrels is fixed a top guide plate.

This arrangement not only provides adequate facilities for expansion; at the same time it divides the vessel into two plenums, coolant entering above the top guide plate, flowing downwards through the core and leaving via the annular space between the core barrels and the vessel itself. A 20 in i.d. inlet nozzle is provided above the top guide plate; two 14 in i.d. outlet nozzles are provided communicating with the annular exit plenum. Other nozzles are provided for pressurization and for thermocouples and core sampling tubes, etc.

The core barrel, in addition to its function of supporting the core, also acts as the first-stage thermal shield. A second thermal shield, totalling 4 in in thickness, is located between the core barrel and the vessel wall.

The vessel is surrounded by heat insulation and by a cavity liner which is set into the main concrete that forms both structural support and biological shield. This cavity liner forms a secondary tank in case of any leakage from the reactor vessel and has no openings below the nozzles in the vessel; a nitrogen atmosphere is maintained in the space between the vessel and the liner.

Coolant

The coolant, which also acts as the moderator, is a mixture of ortho-, meta- and para-terphenyl in the proportions by weight of 10-15%, 55-70% and 20-30% respectively. Some of the physical properties are given in Table 1.

As has already been stated, the direction of the main coolant flow is downwards through the core, leaving by the two outlet nozzles in the reactor vessel.

Two coolant pumps operate in parallel, each having a capacity of 6 000 gal/min against a head of 226 ft. The pumps are of the horizontal centrifugal type, designed for pumping hot oil, with stainless steel impellers and carbon steel casings. Each is provided with a mechanical seal backed up by a labyrinth of aluminium bronze to minimize leakage in case of seal failure, and is driven by a 400 h.p. water-cooled totally enclosed motor.

Table 1. Physical properties of coolant

	519°F	575°F
Density at 30% HB content, g/cm³ ..	0·946	0·921
Viscosity at 30% HB, centipoise	1·03	0·79
Thermal conductivity, Btu/ft² °F h ..	0·0680	0·0666
Hydrogen density at 30% HB, at/cm³ ..	$3·4 \times 10^{22}$	$3·31 \times 10^{22}$
Latent heat of vaporization, Btu/lb ..	127	126
Specific heat at 30% HB, Btu/lb °F ..	0·495	0·502
Water solubility at 510°F (120 psia) 1·4 w/o ; (300 psia) 3·15 w/o		
Melting point at 30% HB content 278°F		
Vapour pressure at 750°F and 30% HB 20 psia		

Fig. 5.—Decay heat exchanger.

From the pumps, the coolant flows to the shell side of the superheater, a shell-and-tube type heat exchanger with ⅝ in U-tubes, the steam being on the tube side. From the superheater, the coolant flow from the two pumps is combined in a single pipe to the boiler, another shell-and-tube unit, with the coolant on the tube side. The shell side incorporates a steam separator, to prevent carry-over of water droplets to the superheater.

From the boiler shell, the coolant flows back to the reactor inlet. A by-pass is provided at the boiler, to reduce the amount of coolant passing through it when the plant is carrying partial loads; this is controlled by a butterfly valve automatically operated by the main control system.

Gate type, motor-operated valves are provided for the reactor inlet, and for both inlet and outlet sides of each pump; the pump discharge sides are also provided with check valves.

The main coolant loop is also provided with a 1 500-gal surge tank, divided into two compartments by a baffle, each half being separately connected to the reactor inlet line, downstream of the inlet shut-off valve.

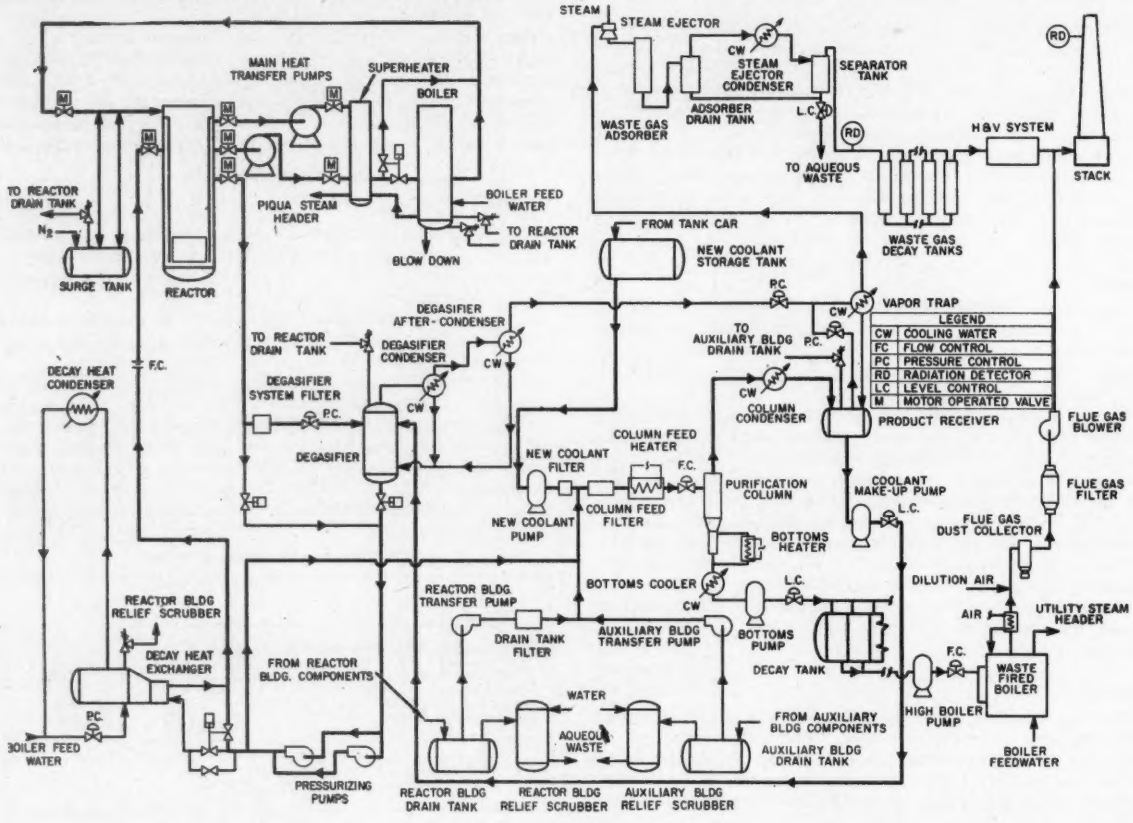
AUXILIARY SYSTEMS

In addition to the main coolant circuit, the plant contains a considerable amount of auxiliary equipment. Radiolytic decomposition of the coolant will produce both gaseous and solid products, both of which must be disposed of. In the event of a scram shut-down where, for any reason, the main heat transfer system is inoperative, some means must be provided for removing the decay heat of the core; it must also be possible to drain the coolant from the reactor tank. It will be convenient to consider these systems separately.

Degasification

Removal of the decomposition gases and any water vapour that might be present (due to small leaks in the heat exchangers) is accomplished by withdrawing coolant from the reactor vessel, removing gas under vacuum and returning it to the reactor vessel by pressurizing pumps.

Fig. 6.—Simplified composite diagram of flow systems.



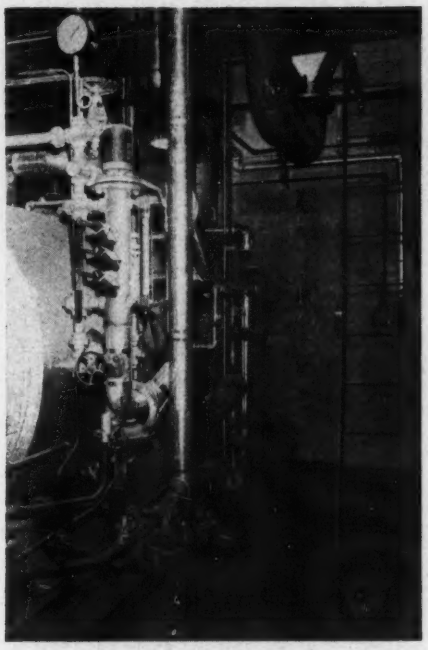


Fig. 7 (left).—Auxiliary boiler for burning HB waste.

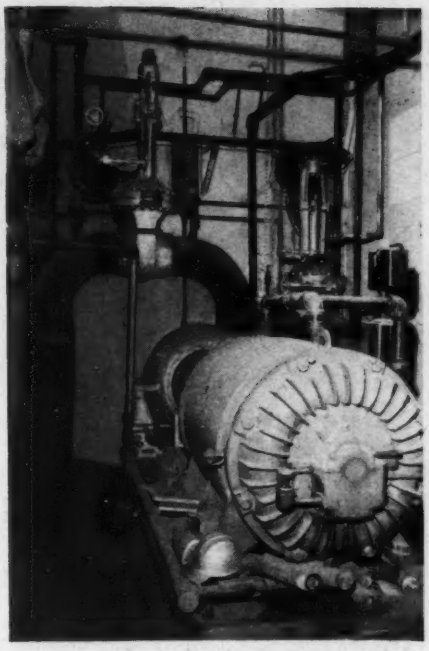


Fig. 8 (right).—Main coolant pump.

The outlet from the reactor vessel is a 6 in pipe extended beneath the level of the main coolant nozzles so that circulation can be maintained even if a large leak in the main coolant circuit causes a drop in level of the coolant. From this pipe the coolant flows through 25 μm filters and back-pressure regulating valves into the degasification tank, which is maintained under vacuum, so that dissolved gas and water flash off. As the flash contains a proportion of evaporated coolant, it is passed through condensers for coolant recovery and the waste gases are discharged to the stack, while the coolant is returned to the reactor vessel by the pressurizing pumps. These are horizontal centrifugal units, with mechanical seals and back-up labyrinths, and are each capable of 200 gal/min against the normal operating pressure of 120 psia.

In emergency, such as loss of main coolant pumping, the filters and degasification tank may be by-passed and the pumps circulate 500 gal/min (from one pump only, if required) through the decay heat exchanger.

The degasification tank has a capacity of 1 500 gal, and serves as an expansion tank to accommodate changes in coolant volume, particularly during start-up and shut-down.

Failed Element Location System

Each position in the core lattice is provided, beneath the lower grid plate, with a $\frac{3}{8}$ in sampling pipe which combines the duties of conveying coolant samples to the FEL system and acting as conduits for the outlet temperature thermocouples. Multiway selector valves are provided. Increased activity in the bulk coolant is the first indication of cladding failure; manual sampling will identify the faulty element. It is claimed that detection of a rupture area of 1 mm^2 is possible.

Decay Heat Removal

For cooling after shut-down, or in emergency, a decay heat exchanger is provided. This is a horizontal shell-and-tube unit with the coolant in the tubes, and water in the shell. Thermosyphon circulation is used on the water side, an open box and immersed coil condenser being provided overhead, with sufficient water capacity above the tubes for one hour of operation if the normal cooling water supply fails.

The decay heat exchanger will remove $2{\cdot}3 \times 10^6$ Btu/h (1·5% of full power) with coolant at 580°F and water boiling at 90 psia (315°F) or $1{\cdot}35 \times 10^6$ Btu/h with coolant at 360°F and water boiling at 58 psia (290°F).

The decay heat exchanger is connected in the coolant return from the pressurizing pumps but is normally by-passed. The by-pass valve is closed and the pumps speeded up at the same time that the degasifier and its filters are by-passed, on the occurrence of a scram signal. The by-pass is controlled by a temperature controller to ensure that the coolant returned to the reactor is maintained at 580°F, after scrams, to prevent increase in reactivity due to temperature coefficient. When this is being used for decay heat removal after a shut-down, no attempt is made to keep up the temperature and no by-passing takes place.

Coolant Purification

Continuous purification of the coolant is provided by the purification loop which also acts as a decontamination system, as the greater part of the activity is contained in the high-boiler (HB) compounds removed in this system.

Coolant from the return side of the pressurizing pumps is withdrawn at a controlled rate and, together with new coolant, is passed through 5-10 μm filters to a heater where it is heated to 700°F before passing to a distillation column, where it flashes to vapour leaving the high-boiler content as "bottoms" to be pumped away to the HB decay tanks, before being transferred to the waste disposal system. The flash is condensed and flows to the receiving tank, whence it is later pumped by the make-up pumps to the degasifier tank for return to the coolant system.

Relief, Drain and Vent System

All equipment which may be subject to over-pressure is provided with relief devices of appropriate design and setting; the relief valves for the main heat transfer system, for example, are set at 285 psi. All relief valves handling organic coolant are of the bellows-sealed pattern and are isolated from the coolant by rupture discs. Vents are piped to one of two main pressure relief headers; inside the reactor building this leads to the reactor building drain tank, in the auxiliary building all systems drain into the auxiliary drain tank.

From the reactor drain tank all vapour is discharged to a counter-current water scrubber; after monitoring, it is discharged to the stack via the exhaust ventilation system.

Waste Disposal Systems

Three types of waste have to be considered; gaseous wastes from the degasifier and purification system, organic wastes (high-boilers) and aqueous wastes from various process systems.

Waste gases flow through an organic trap (where the

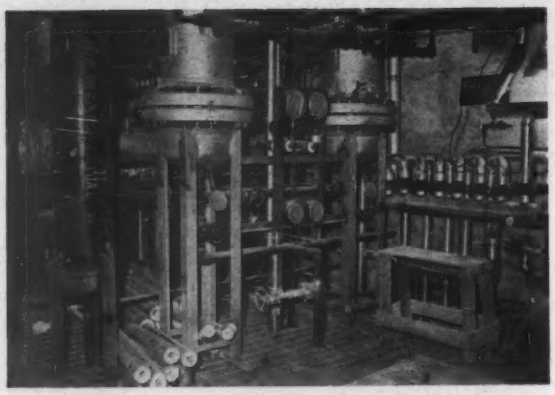


Fig. 9.—Purification room, showing filters under erection.

temperature is lowered to about 160°F to remove diphenyl and terphenyl compounds) to a steam ejector from which they pass through activated-charcoal adsorbers to remove the remainder of these compounds. From these they pass through a separator, a condenser and a second separator; the liquid residues from these, including the condensed ejector steam, are piped to the aqueous waste system. The gas is then piped to a series of decay tanks, of which there are 22, each 10 in diameter and 15 ft high, eight being filled with activated charcoal. From the decay tanks, the gases are released to the stack via the exhaust ventilating system.

The estimated rate at which high-boiler compounds are formed is 60 lb/h maximum, and HB storage tanks are sized to contain six months' accumulation. Disposal is by burning, it having been established by experiment that this can be carried out without ash residue. A small steam boiler (900 lb/h) is employed, the high-boilers being burned in the furnace in burners similar to those employed for fuel oil. The flue gas is diluted with air and passes through filters on its way to the stack.

Alternative methods of HB disposal, involving shielded shipment and off-site burial, might be adopted if it is found that residues contain undesirable concentrations of long-lived activity not removed by the filters. Analysis of compounds produced in OMRE, however, indicates that burning should be perfectly satisfactory.

Aqueous wastes can be divided into two classes. Sanitary wastes, cooling water, rain water, etc., are monitored and discharged to the Miami River through the main effluent line.

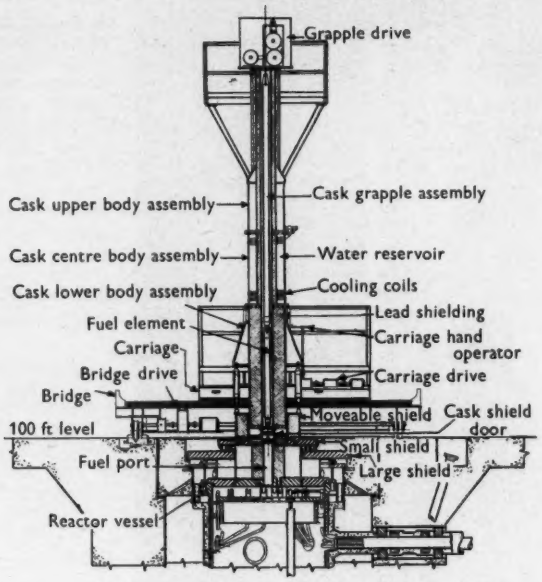
All other aqueous wastes collect in the sumps either of the reactor building or of the process building, from which they are pumped to a settling basin, and liquids and particulate matter either lighter or heavier than water are removed for burning along with the high-boiler residue. Those of intermediate density are pumped through filters and diatomaceous earth absorbers to one of the first four compartments in the aqueous waste hold-up tank, the other two compartments receiving condensate from the steam ejector in the waste gas system. It is finally discharged to the sanitary sewer system if sampling shows that levels below MPC are possible after the normal dilution with cooling water.

Other auxiliary systems provided include storage and handling of new coolant, a preheating system to provide steam tracing wherever necessary to maintain the organic coolant in a liquid condition, and a nitrogen purging system for providing blanket atmospheres where necessary and for pressure transfer of coolant between tanks.

Fuel Handling

Replacement of some 25% of the core (15-20 elements) will take place at each shut-down, i.e., every four-six months. After shut-down and decay cooling, the reactor head is removed and replaced by a rotating shield assembly containing two eccentrically mounted rotating shields so that the fuel port in the inner shield can be located in any desired position. The

Fig 10.—Section of refuelling machine.



operation of removing the vessel head and installing the rotating shield assembly is carried out by means of the polar crane above the reactor floor.

The actual refuelling machine consists of a shielded cask containing the necessary grappling and hoisting mechanisms, shield door and cooling system, which is mounted on an indexing carriage on a bridge travelling on rails spanning the reactor. By a combination of bridge and carriage movements the cask may be located over the fuelling port in the rotating shield, and a short concentric sliding skirt can be lowered to act as a transition shield.

Cooling equipment is provided in the event that it is needed during transfer. The door closing the cask is hydraulically operated and makes a tight seal. In case of a failure of the grappling mechanism, provision is made for flooding the cask with mono-isopropyl-biphenyl, cooling the element by forced convection, this liquid itself being cooled by water in coils. Natural convection of the cooling liquid can replace forced convection in case of pump failure; if required, the cask can be flooded with water.

The cask, with an irradiated element, is transported along the rails to the fuel storage pool, an L-shaped tank containing demineralized water. The unloading station has heavy concrete shielding above the pool and a lead-shielded snout over which the fuel cask is located. The element is lowered into a turret which can be indexed round to receive a number of elements; these are afterwards transferred singly to stainless steel storage racks, sub-critically spaced, by means of an auxiliary hoist on the polar crane. This is also used for transferring elements to the shipping container for dispatch to the reprocessing centre; the loading of the shipping cask is carried out under water.

Plant Control and Safety

Overall control philosophy of the Piqua plant is to provide flexibility comparable with that of a conventional steam plant, including automatic load following from 20% to 100% full load; manual control is used for start-up and may be introduced at any value of load if so desired. The control programme is based on constant reactor outlet temperature and constant coolant flow; reactor power is varied by control rod adjustment and inlet temperature is varied by adjusting the rate of heat removal by means of the boiler by-pass system, the boiler feed rate being adjusted at the same time.

The 13 control rods are divided into three groups or zones; the centre rod (No. 1), the middle ring (Nos. 2-7) and the

outer ring (Nos. 8-13). Each rod is provided with individual selection switches to enable it to be connected to one of three driver units so that it functions as regulation, shim or safety rod, as required. Switches are interlocked so that it is not possible to select two drivers for one rod.

Scramming of the reactor, by the simultaneous de-energizing of the magnetic jacks, occurs on signals being received from five coincident circuits and any of five independent circuits. The coincident circuits (two out of three) include high outlet temperature, high inlet temperature, high power/flow ratio, high or low system pressures. The five independent trips operate for manual scram, loss of power to coolant pumps, loss of power to pressurizer pumps, low degasifier tank level or short doubling time on the intermediate flux range.

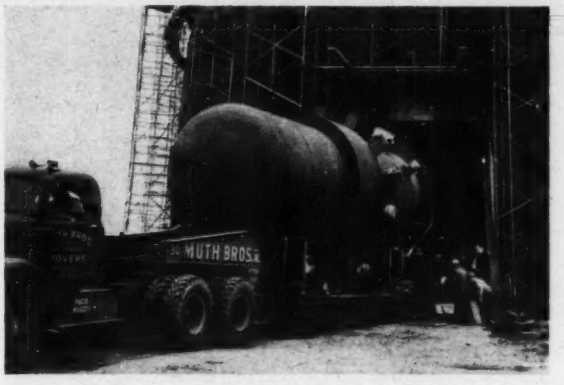
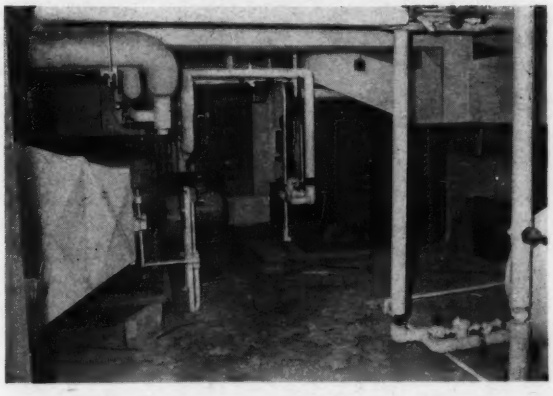


Fig. 11 (above).—Pressure vessel arriving on site.

Fig. 12 (below).—Part of air-conditioning plant in the auxiliary building.



In addition to the scram circuits there are automatic "set-back" circuits, energized for conditions which can be rectified by a reduction in reactor power level. Three rods are inserted at normal driving speed until the off-normal condition ceases to exist; if this set-back does not correct matters, a scram follows.

Shielding

Thermal shielding of the core is provided by the lower core support barrel, 1½ in thick, which surrounds the core, and by two other concentric mild steel cylinders, with a total thickness of 4 in, between the core and the vessel wall. The heat generation in these two shields is approximately 2% and 0·5% respectively, of the full load reactor output.

Biological shielding around the vessel is provided by 6 ft of ordinary concrete, surrounding the core cavity liner; coils with circulating water surround this liner in the region of the core.

The nitrogen-filled annular region between the vessel, which

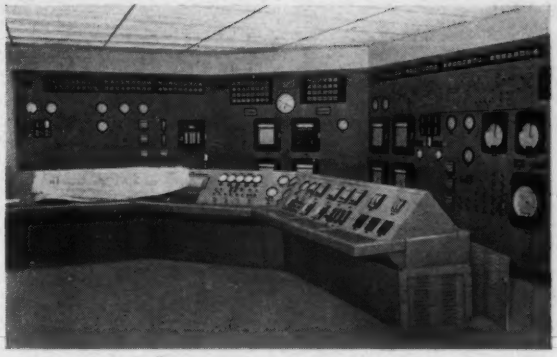


Fig. 13.—Part of control room during erection.

is covered with thermal insulation, and the cavity liner is provided with a gas seal in the region of the support brackets; above this is an annular tank containing about 2 ft thickness of serpentine aggregate shielding to prevent radiation streaming from the annulus.

The core itself is at the bottom of a deep vessel filled with moderator and has a steel head 9 in thick; as all other active areas such as the main coolant loop are covered by concrete, the reactor floor is scheduled as an "unlimited access" area.

Ventilation

Ventilation to the reactor building is at a maximum rate of 32 700 ft³/min. Air is taken from outside the building by the supply fan through a damper, an automatic roll-type filter and two air-operated rapid-closing butterfly valves.

The exhaust air from each process unit within the building is collected, through individual filters, into a common header which penetrates the building via two rapid-closing valves; the duct passes to the process building, where it is exhausted through absolute filters, to the stack. By regulation of the inlet damper, the reactor building is maintained ⅛-¼ in w.g. below atmospheric pressure so that any leakage is in an inwards direction. In the same manner, the flow within the building is always towards areas of potential contamination. Heating and cooling equipment is installed so that the minimum air temperature in winter is 60°F and the maximum in summer, 115°F.

In the event of contamination, the inlet and outlet valves are automatically closed to seal the building. Vacuum-breaker

Fig. 14.—Control room; health monitoring panel.

Table 2. Summary of Potential Hazards (based on postulated failures and resultant incidents)
Note. Incidents marked * are not considered credible

Incident	System failure	Remarks
	1. Nuclear Incidents	
(a) Startup transient 100% flow—protective system operable.	Control system failure. No action by operator	Max. fuel cladding temp. is less than 750°F for backup scram setpoint of 120%.
(b) Startup transient 100% flow—protective system inoperable.	Control system failure. No action by operator. Protective system failure.	Melting of 50% of six centre elements causes ultimate shutdown. Max. dose rate at nearest residence = 0·1 mr/hr, decreasing to 0·004 mr/hr after 24 hr.
(c) Startup transient 60% flow—protective system operable.	Control system failure. No action by operator	Max. fuel cladding temp. is 675°F for backup scram setpoint of 75% power.
(d) Startup transient 60% flow—protective system inoperable.	Control system failure. No action by operator. Protective system failure.	Same as 1(b).
(e) Control rod withdrawal at operating power—protective system operable.	Control system failure. No action by operator	Max. fuel cladding temp. is 817°F for backup scram setpoint of 585°F.
(f) Control rod withdrawal at operating power—protective system inoperable.	Control system failure. No action by operator. Protective system failure.	Same as 1(b) except that less energy is released before shutdown.
(g) Cold coolant introduced into core coolant	Faulty action by operator	Since there is only one loop, there is only a small amount of cold coolant available.
(h) Loss of main coolant flow	Loss of power to both pumps	Decay heat system operable—peak metal temperature 725°F.
(i) Loss of coolant pressure. No system rupture.	Pressurizing system failure	Gradual loss of pressure allows protective system action. No melting of fuel.
(i) Loss of coolant pressure. System rupture.	Rupture of main heat transfer system	Maximum fuel plate temperature is less than 718°F.
	2. Substitution of Water* for the terphenyls in the core	
	Deliberate addition of water to the reactor	Reactivity is decreased. Reactor is subcritical.
	3. System Incidents	
(a) Major water leak into heat transfer system.	Failure of steam boiler tube	Relief valves lift and maintain coolant system pressure at 300 psia.
(b) Loss of coolant from core tank	Core tank ruptures	Core cavity liner retains coolant. Decay heat system continues operation.
(c) Loss of coolant from process piping	(1) Process piping ruptures	(1) Fire protection system actuated. Max. press. 0·85 psi with ventilation system open.
	(2) Process piping ruptures	(2) Fire protection system actuated. Max. press. 3·0 psi with ventilation system closed at time of incident.*
(d) Steam system rupture. (Small leak)	Leak in boiler	Building press. rise is 1·2 psi for a 4·6-in hole in steam line.
(e) Steam boiler rupture. Ventilation system open.	(1) Complete rupture of boiler, maximum water hold up (no load). No cooling.	(1) Water flashes. Building press. rises to 3·85 psi.
	(2) Complete rupture of boiler, normal water hold up (100% load). No cooling.	(2) Water flashes. Building press. rises to 1·95 psi.
(f) Steam boiler rupture. Ventilation system closed.	(1) Simultaneous boiler failure and ventilation system failure. Maximum boiler water hold up (no load).	(1) Water flashes. Building press. peaks at 4·9 psi.
	(2) Simultaneous boiler failure and ventilation system failure. Normal boiler water hold up (100% load).	(2) Water flashes. Building press. peaks at 2·45 psi.*
(g) Steam boiler rupture. Organic coolant spill. Ventilation system open 2 minutes.	Simultaneous boiler and coolant system rupture. Maximum boiler water hold up (no load).	Peak building press. is 3·85 psi. Decreases to 1 psi.*
(h) Coolant fire in reactor cavity	Core tank rupture. N_2 lost. Ignition source necessary.	Fire will snuff itself out.*
(i) Coolant fire inside core tank	Operator must open reactor with coolant above 460°F. Ignition source necessary.	Fire will snuff itself out—or operators will extinguish blaze.
(i) Coolant fire in Process area	Piping ruptures. Ignition source necessary	Air supply closes. Fire protection system extinguishes fire. Peak pressure 2·8 psi with ventilation ducts closed.
(k) Coolant dust explosions	Atomizing type leak. Warning system failure. Ignition source available.	Volume of mixture in explosive range is small. Max. press. is 1·2 psi.
(l) Coolant vapour explosions	Coolant system rupture. Fire protection system failure. Ignition source available.*	Volume of explosive mixture is small. Max. pressure rise in reactor building is 0·2 psi.
(m) Uranium alloy reaction with H_2	Fuel element cladding failure. Fuel element at low temperature. System operated without degasifier*	H_2 partial pressure in coolant, too low to react with exposed U.
(n) Earthquakes and floods	Acts of God	Plant protected against floods and designed to withstand earthquakes.
	4. Radiation Releases From Coolant (No Fission Products)	
(a) Coolant spill	System rupture	Stack release. Air activity at ground level is $6{\cdot}8\times10^{-9}\mu c/cm^3$.
(b) Coolant fire in reactor building. No protective action.	System rupture. Ignition source necessary. Fire protection system fails.*	Stack release. Total inhaled activity is $0{\cdot}7\times10^{-2}\mu c/cm^3$.
(c) Coolant fire in auxiliary building. No protective action.	System rupture. Ignition source necessary. Fire protection system fails.*	Ground release. Total inhaled activity is 2·5μc.
	5. Fission Product Release	
(a) Fuel handling	Fuel cask handling system fails. Normal cooling system fails. Emergency cooling system fails. Cask door fails to close.*	Whole body dose of 3.5 r in one week, and 8·2 r in one month at nearest residence.
(b) Core meltdown and release of fission product to reactor building.	Nuclear incident, system rupture.*	10% of all gaseous fission products released. Direct radiation whole body dose at nearest residence = 4·5 r in one week and 6 r in one month. Dose from cloud is 1·0 rem in one week.

valves are provided to operate if the shell pressure is less than 0·5 psi below atmospheric.

An additional exhaust system is provided for use when the reactor is shut down and the head removed for fuel changing, to capture any organic fumes or active dust. It consists of a plenum surrounding the core tank just beneath floor level, with two exhaust ducts and an additional exhaust fan.

Ventilation and Safety Precautions

Ventilation to the auxiliary building consists of one main supply fan and two exhaust fans discharging to the main stack. As in the case of the reactor building, the incoming air is filtered, and the exhaust is fitted with pre-filters and absolute filters and the air flow throughout is towards areas of potential contamination. A separate air-conditioning unit supplies de-humidified air to the control room, instrument repair room and health physics counting room.

An analysis of potential hazards, due to combination of incidents has been made, and conclusions drawn as to their credibility. Results are summarized in Table 2.

It is concluded that the maximum credible incident would be caused by the uncontrolled withdrawal of control rods during start-up. This incident would be terminated by void formation and the melt-down of 50% of the six centre elements, which could release 7·5% of the core fission products. The total energy release during this transient would be 2 750 MWs, which would cause a coolant temperature rise of less than 100°F, and a very small pressure rise, so that the integrity of the coolant system would be maintained. The dose rate at the nearest residence due to fission products in the coolant would be 0·1 mr/h at the time, decaying to 0·004 mr/h after 24 h, and the TID for one week would be less than 0·1 r.

Acknowledgment

We are indebted to the Atomics International Division of North American Aviation, Inc., for access to the Hazards Report on which this article is based.

The

No. 3

OWNER:	U
BUILDER:	A
OPERATOR:	C
PURPOSE:	P
LOCATION:	S
TYPE:	T
PROGRAMME:	C C
CAPACITY:	4 1
FUEL:	E A U F C Ir A C S. L M *T*
CORE:	D L/ La N C H C A *k* To Th Pe Ex Eq Bu Fl
CONTROL:	N M To Sh Ac Di Ma Re To
COOLANT/ MODERATOR:	Iso In Ou Flo Ma No Pr Bo He

The World's Reactors

No. 35 Piqua Nuclear Power Facility

U.S. Atomic Energy Commission.

Atomics International.

OR: City of Piqua.

Power demonstration (supplying steam to existing generating equipment).

N: S.E. of the city of Piqua, Ohio.

Thermal, heterogeneous, organic moderated and cooled.

MME: Construction commenced: July 1959.
Operation: Spring 1962.

Y: 45·5 MW(th).
11·4 MW(e) net.

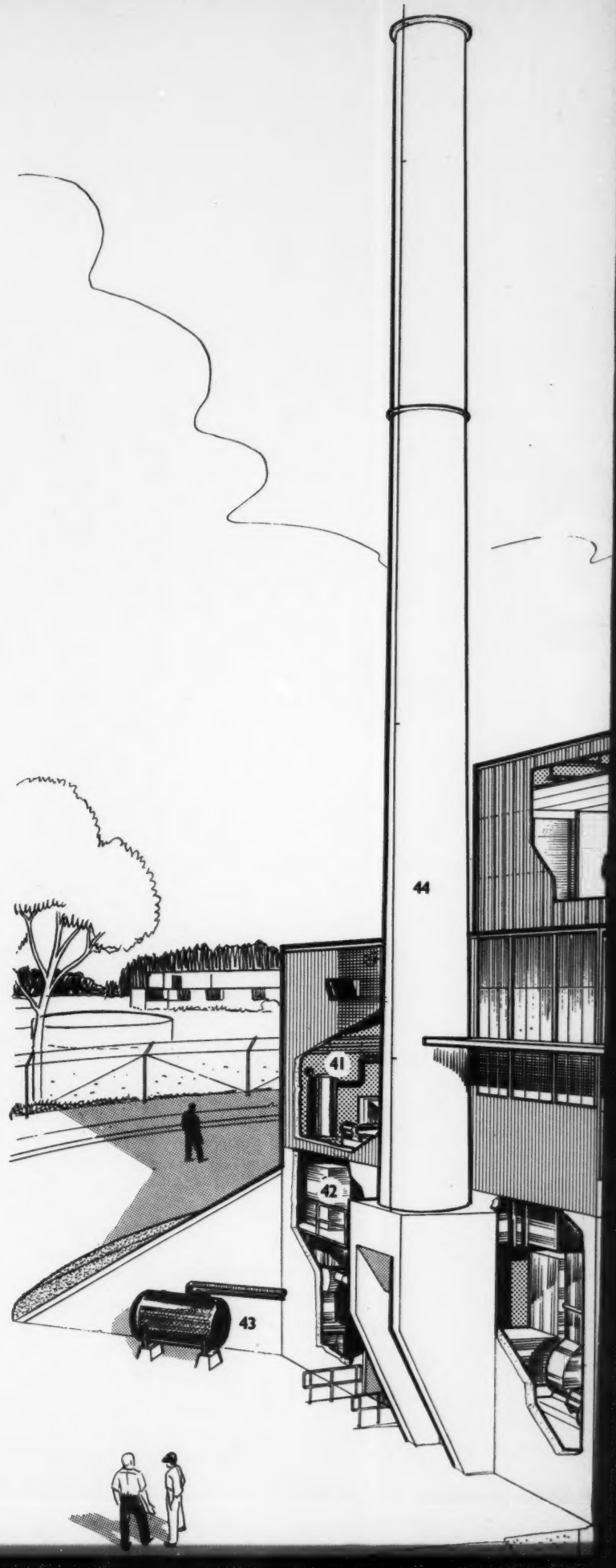
Enriched (1·94%) U alloy.
Alloy: 3·5 w/o Mo, 0·1 w/o Al.
U^{235} investment: 134 kg.
Fuel elements comprise two concentric alloy tubes in s.s. tubular channel, 5·21 in o.d. × 3·08 in i.d.
Outer fuel tube: 4·63 in mean dia.
Inner tube: 3·60 in mean dia.
Alloy thickness in each tube: 0·208 in.
Cladding: finned aluminium, 0·035 in wall.
S.S. channel wall: 0·01 in.
Length of element: active 54 in, overall 80·5 in.
Max. allowable surface temp. (steady state): 750°F (399°C).
T_{sm} at rated power: 713°F (378°C) at core periphery (limiting element);
701°F (372°C) (max. power element).

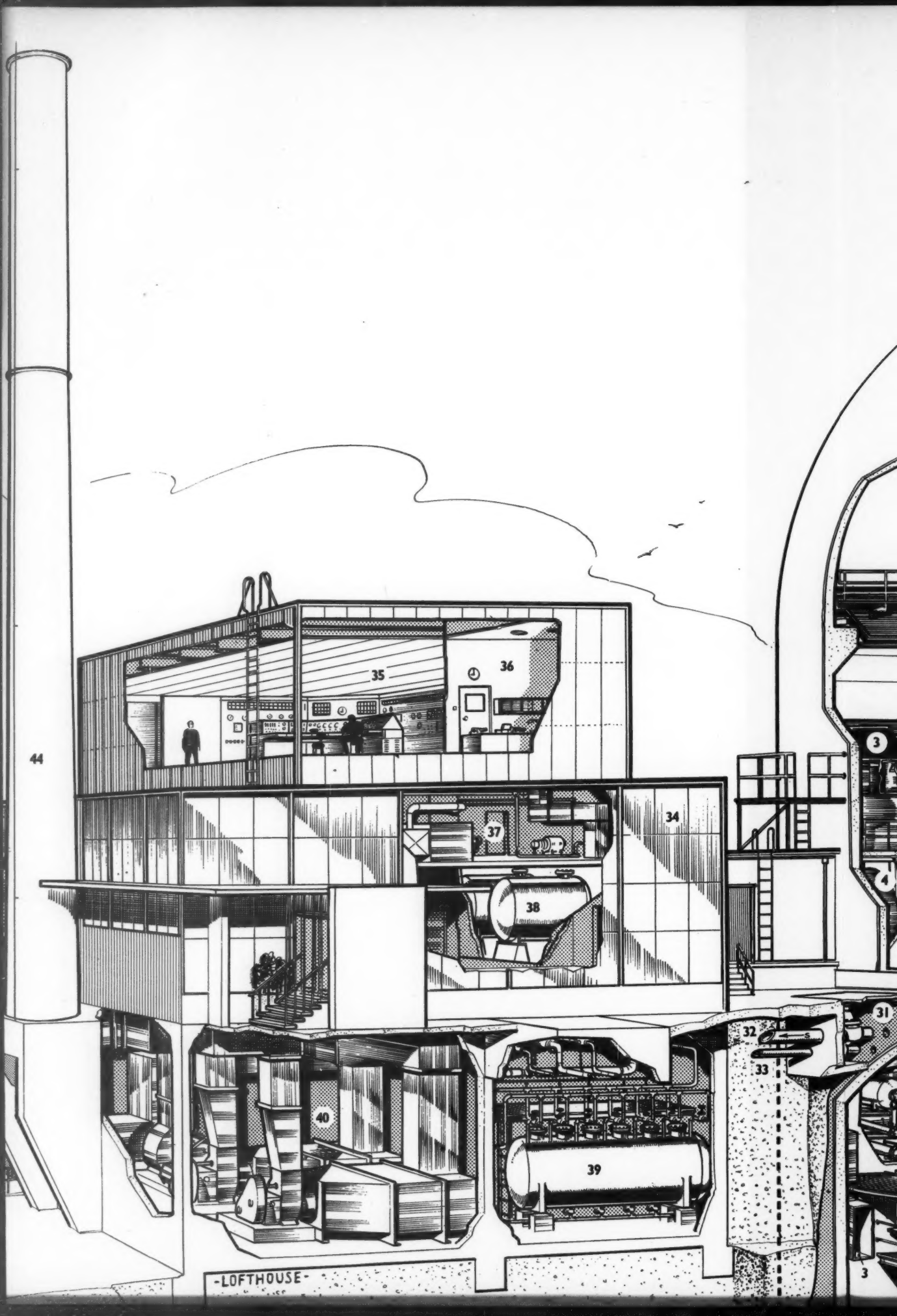
Dimensions: approx. cylinder, 60 in dia.
L/D ratio of core: 1·23.
Lattice: 6 in triangular pitch.
No. of elements: 85.
Core loading: 6 900 kg U.
Heat flux in core: max., 89 500 Btu/ft²h;
average: 34 600 Btu/ft²h;
burn-out: 450 000 Btu/ft²h.
Core composition (v/o): U alloy, 17·2%; moderator 69·9%.
Al, 12·1%; stainless steel 0·8%.
Average burn-up per element: 275 MWd.
k_{eff}, hot, clean: 1·068.
Temperature coefficient (550°F): $-7{\cdot}5\times10^{-5}$/°F.
Thermal flux in fuel: av., $1{\cdot}4\times10^{13}$ n/cm²s;
max., $5{\cdot}5\times10^{13}$ n/cm²s.
Peak/average flux ratios, radial and axial, 1·47.
Excess reactivity at start of equilibrium burn-up cycle (hot): 6·8%
Equilibrium Xe and Sm .. .. 3·2%
Burn-up .. .. 1·8%
Flux flattening and control margin .. .. 1·8%

L: No. of control rods: 13.
Material: Boron carbide.
Total worth: 12·2% $\Delta k/k$.
Shutdown margin: 4·34 $\Delta k/k$.
Active length: 48 in, travel: 48 in.
Diameter: 2·582 in.
Max. withdrawal rate: 0·008% Δk/s.
Release time: 0·08 s.
Total scram time: 0·725 s.

T/ ATOR: Isomeric mixture of ortho- meta- and para-terphenyls.
Inlet temperature: 518°F (270°C).
Outlet temperature: 575°F (301°C).
Flow rate: 12 000 gal/min ($5{\cdot}5\times10^{6}$ lb/h).
Max. coolant velocity through fuel element: 12·7 ft/s.
Normal operating pressure: 120 psia.
Pressure drop through core: 27 psi.
Boiling point at minimum operating pressure: 913°F (489°C);
at atmospheric pressure: 700°F (371°C).
Heat transfer coefficient (max.): 1 300 Btu/ft²h.

Design pressure: 300 psi.

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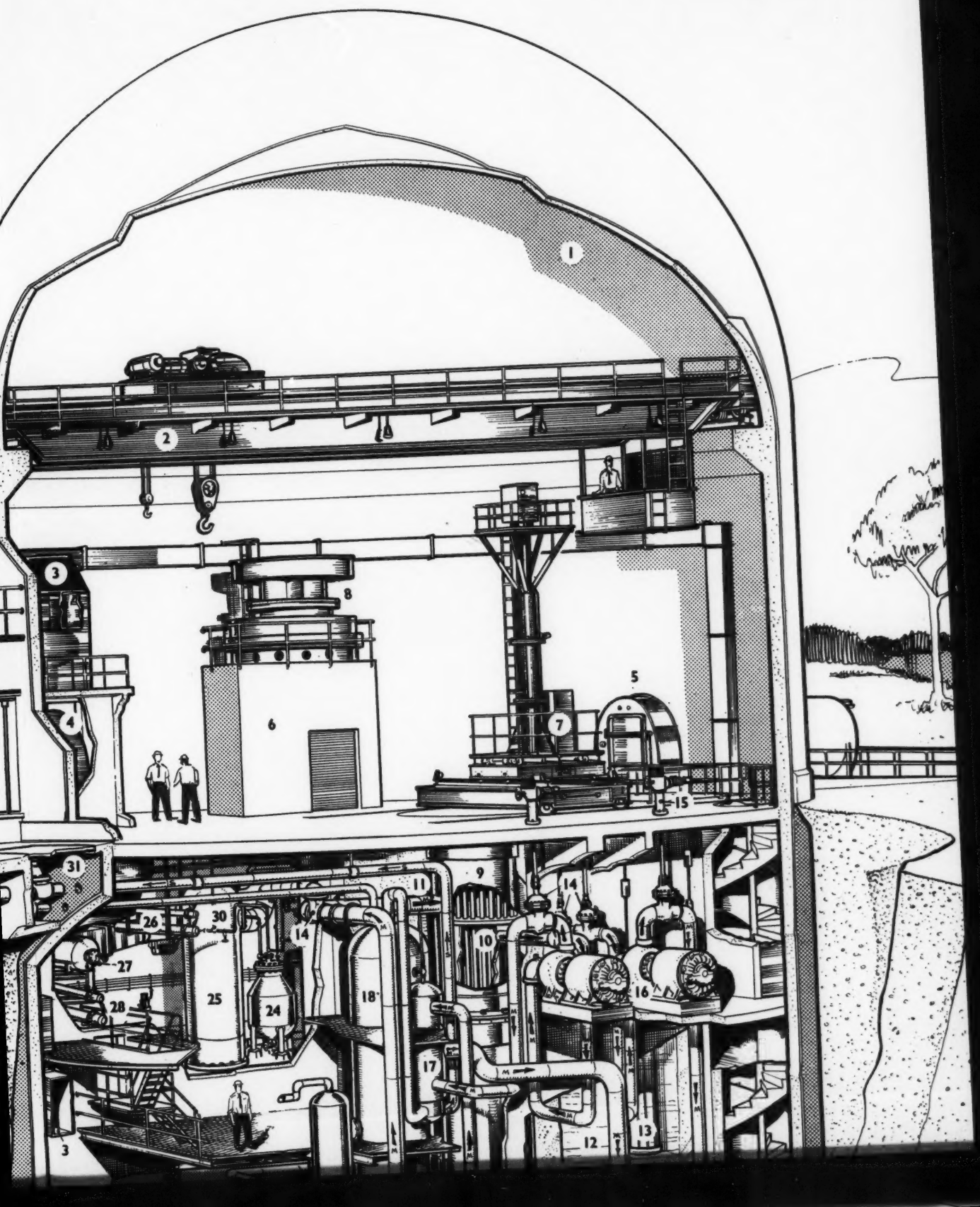
Piqua



PROGRAMME:	C O
CAPACITY:	45 11
FUEL:	Er Al U Fu O In Al Cl S. Le M T_s
CORE:	Di L/ La N C H C A k_e Te Th Pe Ex Eq Bu Fl
CONTROL:	N M To Sh Ac Di M Re To
COOLANT/ MODERATOR:	Iso Ini O Fl M N Pr Bo He
PRESSURE VESSEL:	De He Ins M Th
HEAT TRANSFER:	N Ca To Pr Pu Co Va Co Co He Co Co Fe
STEAM CONDITIONS:	Dr Te St He Su
SHIELDING:	Th Bi

Printed in England by Temple Pr

IME:

Operation: Spring 1962.

:

45·5 MW(th).
11·4 MW(e) net.

Enriched (1·94%) U alloy.
Alloy: 3·5 w/o Mo, 0·1 w/o Al.
U^{235} investment: 134 kg.
Fuel elements comprise two concentric alloy tubes in s.s. tubular channel, 5·21 in o.d. × 3·08 in i.d.
Outer fuel tube: 4·63 in mean dia.
Inner tube: 3·60 in mean dia.
Alloy thickness in each tube: 0·208 in.
Cladding: finned aluminium, 0·035 in wall.
S.S. channel wall: 0·01 in.
Length of element: active 54 in, overall 80·5 in.
Max. allowable surface temp. (steady state): 750°F (399°C).
T_{sm} at rated power: 713°F (378°C) at core periphery (limiting element);
701°F (372°C) (max. power element).

Dimensions: approx. cylinder, 60 in dia.
L/D ratio of core: 1·23.
Lattice: 6 in triangular pitch.
No. of elements: 85.
Core loading: 6 900 kg U.
Heat flux in core: max., 89 500 Btu/ft²h;
average: 34 600 Btu/ft²h;
burn-out: 450 000 Btu/ft²h.
Core composition (v/o): U alloy, 17·2%; moderator 69·9%.
Al, 12·1%; stainless steel 0·8%.
Average burn-up per element: 275 MWd.
k_{eff}, hot, clean: 1·068.
Temperature coefficient (550°F): $-7{\cdot}5\times10^{-5}$/°F.
Thermal flux in fuel: av., $1{\cdot}4\times10^{13}$ n/cm²s;
max., $5{\cdot}5\times10^{13}$ n/cm²s.
Peak/average flux ratios, radial and axial, 1·47.
Excess reactivity at start of equilibrium burn-up cycle (hot): 6·8%
Equilibrium Xe and Sm .. .. 3·2%
Burn-up .. .. 1·8%
Flux flattening and control margin .. .. 1·8%

:

No. of control rods: 13.
Material: Boron carbide.
Total worth: 12·2% $\Delta k/k$.
Shutdown margin: 4·34 $\Delta k/k$.
Active length: 48 in, travel: 48 in.
Diameter: 2·582 in.
Max. withdrawal rate: 0·008% Δk/s.
Release time: 0·08 s.
Total scram time: 0·725 s.

/
ATOR:

Isomeric mixture of ortho- meta- and para-terphenyls.
Inlet temperature: 518°F (270°C).
Outlet temperature: 575°F (301°C).
Flow rate: 12 000 gal/min ($5{\cdot}5\times10^6$ lb/h).
Max. coolant velocity through fuel element: 12·7 ft/s.
Normal operating pressure: 120 psia.
Pressure drop through core: 27 psi.
Boiling point at minimum operating pressure: 913°F (489°C);
at atmospheric pressure: 700°F (371°C).
Heat transfer coefficient (max.): 1 300 Btu/ft²h.

Design pressure: 300 psi.
Height: 27 ft 3½ in.
Inside diameter: 92 in.
Material: Carbon steel.
Thickness: 2½ in and 1⅛ in.

ER:

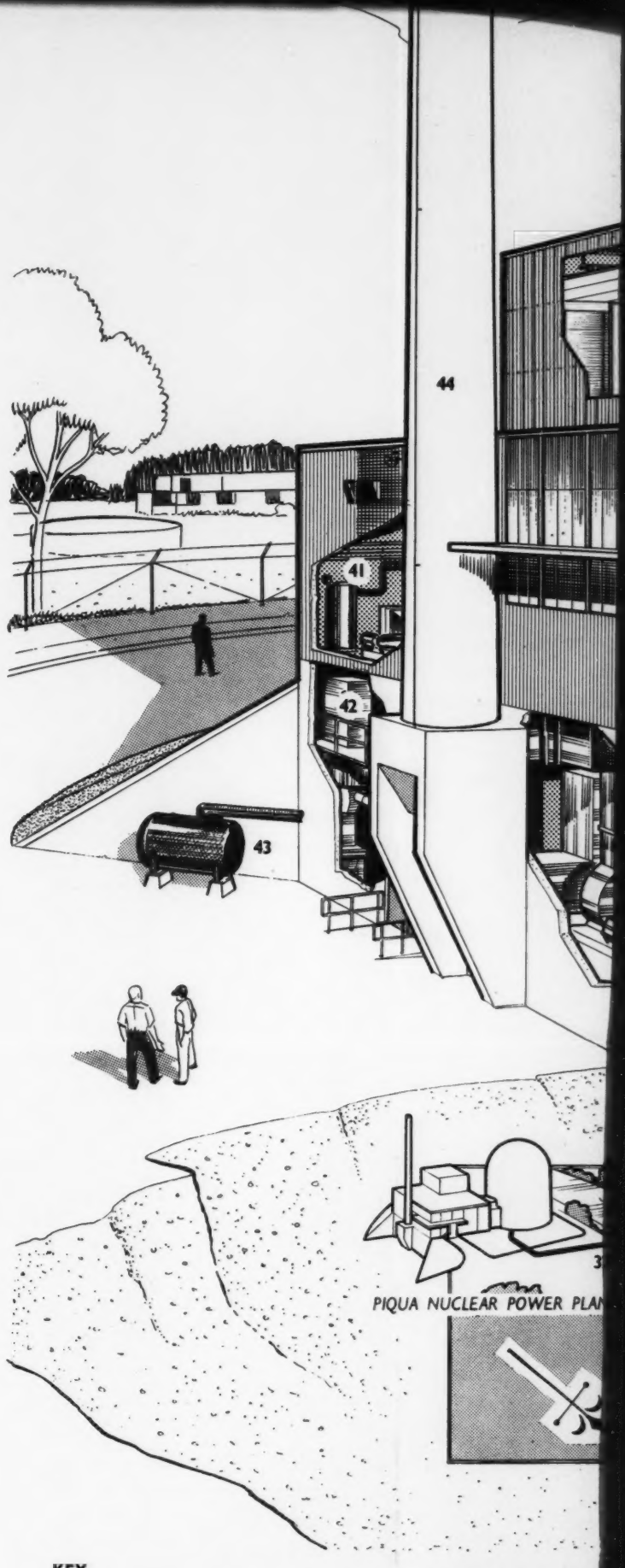
No. of coolant pumps: 2 in parallel.
Capacity: 6 000 gal/min each.
Total pressure drop, main loop: 90 psi.
Pressurizing pump flow rate: 200 gal/min.
Purification flow rate: 258 lb/h.
Coolant make-up: 60 lb/h.
Volume of heat transfer system (total): 13 300 gal.
Core tank volume: 7 700 gal.
Core tank volume below coolant nozzles: 4 600 gal.
Heat required to raise temperature of coolant below nozzles from inlet temperature to atmospheric boiling point: $3{\cdot}4\times10^6$ Btu.
Coolant temp. entering superheater: 575°F (301·6°C).
Coolant temp. entering boiler: 571·3°F (299°C).
Feedwater temperature: 268°F (131°C).

IONS:

Drum pressure: 445 psi.
Temp. at superheater: 550°F (288°C).
Steam flow: 150 000 lb/h.
Heat duty (boiler): $145{\cdot}3\times10^6$ Btu/h.
Superheater: 103×10^6 Btu/h.

G:

Thermal shielding: concentric carbon steel shields inside tank, inner 1·5 in, outer 4 in thick.
Biological shielding: Ordinary concrete, 8 ft thick.



KEY

1. Containment building
2. Polar crane
3. Ventilation equipment
4. Personnel airlock
5. Equipment airlock
6. New fuel storage ro
7. Fuel handling cask
8. Rotating cover (in s
9. Reactor
10. Coolant outlets
11. Coolant inlet
12. Fuel storage pool

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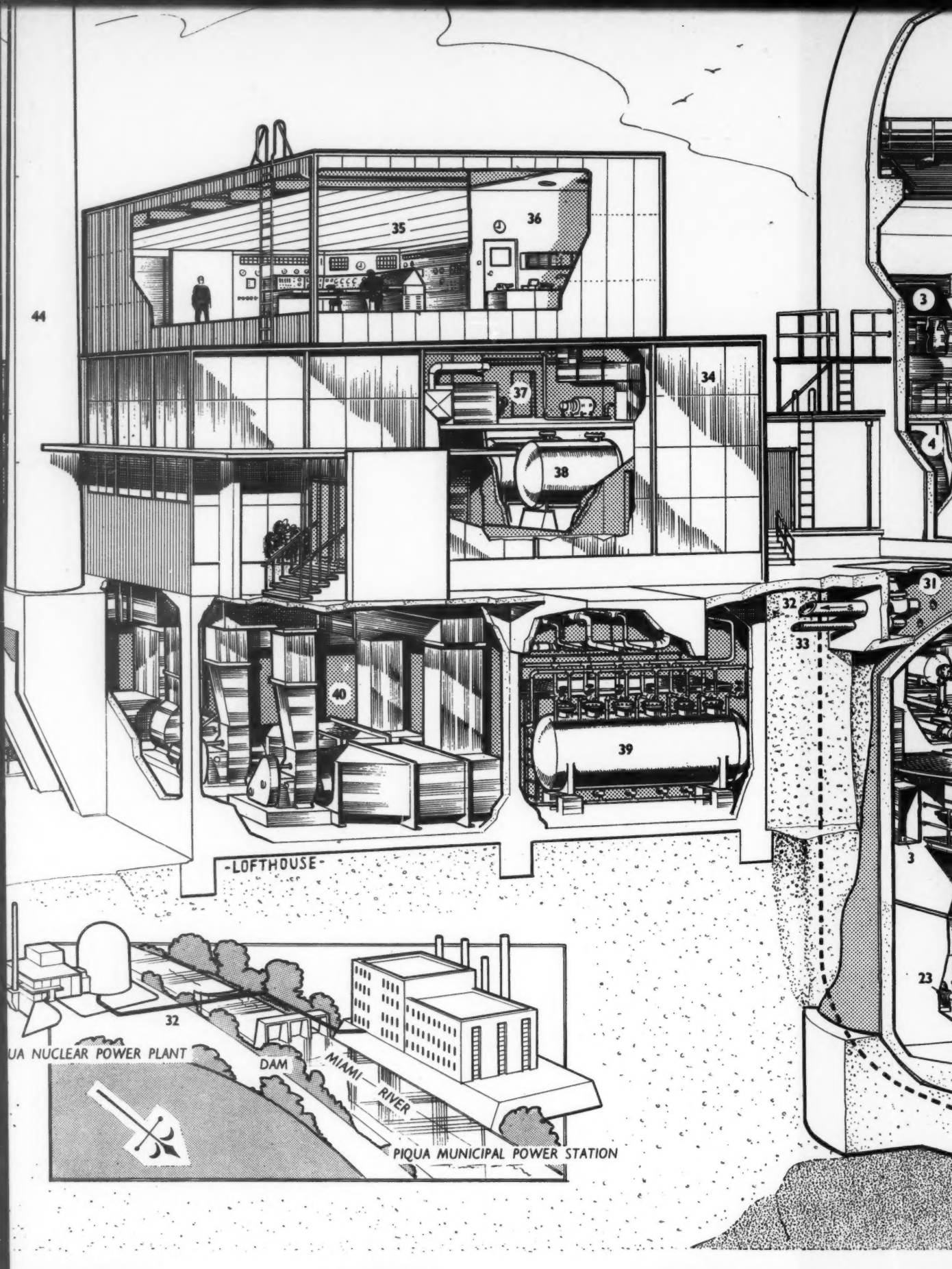

6. New fuel storage room
7. Fuel handling cask
8. Rotating cover (in storage)
9. Reactor
10. Coolant outlets
11. Coolant inlet
12. Fuel storage pool
13. Shipping cask
14. Motorized valves
15. Valve actuators
16. Primary coolant pumps
17. Superheater
18. Boiler
19. Surge tank
20. Relief scrubber
21. Reactor building drain tank
22. Decay heat exchanger
23. Pressurizing pumps
24. F.E.L.S. tank
25. Degasifier
26. Degasifier condensers
27.
28.
29.
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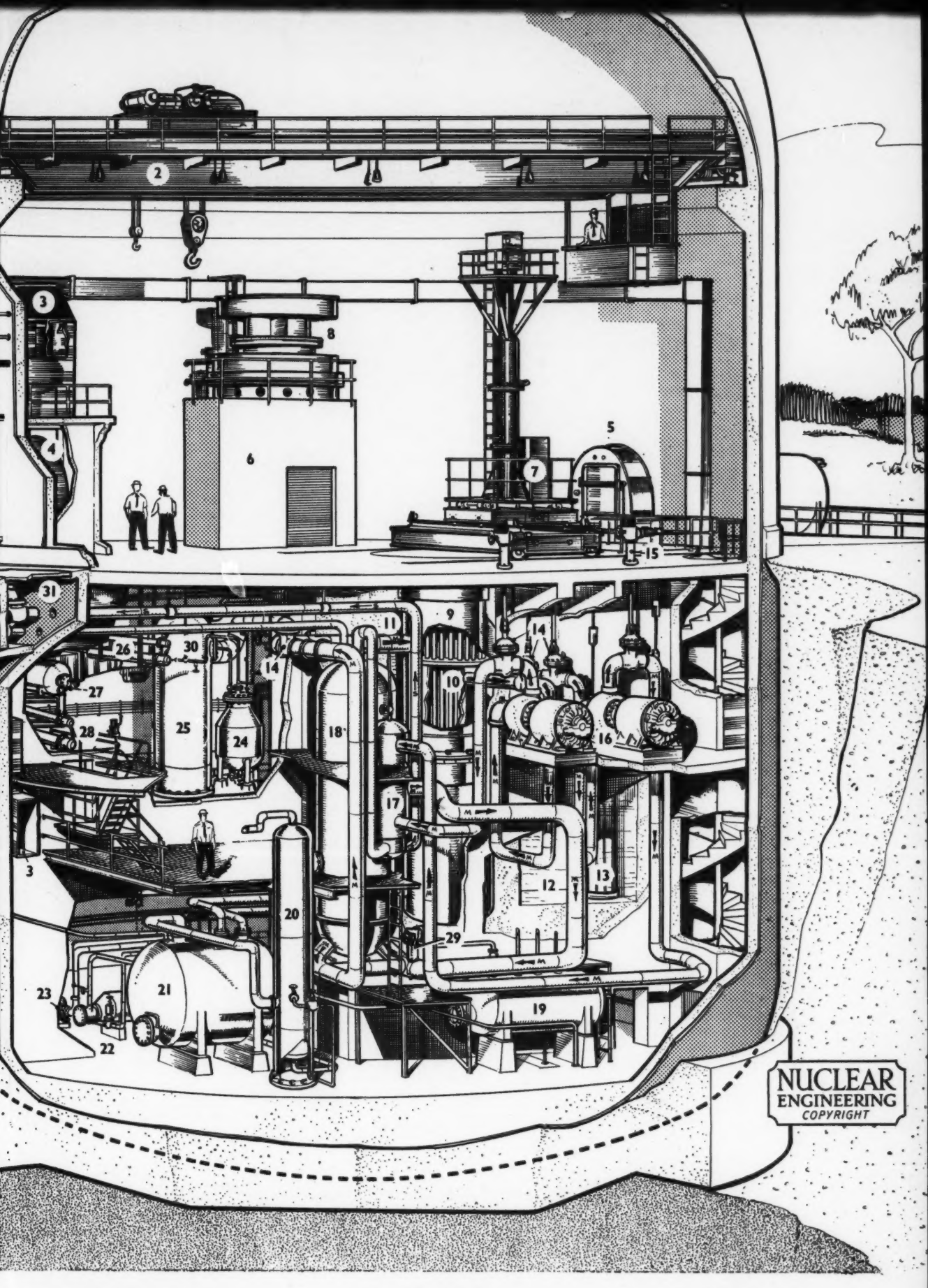
32.
33.



27. Shield cooling tank
28. Shield cooling heat exchanger
29. Bypass control valve
30. Purification bleed
31. Valve pit
32. Main steam line
33. Steam dump line
34. Auxiliary building
35. Control room
36. Instrument repair shop
37. Heating and ventilating room
38. New coolant storage tanks (outside)
39. Aqueous waste tank
40. Exhaust and filter room
41. Compressor room
42. Waste fired boiler room
43. Propane tank
44. Stack
M. Moderator/coolant
S. Steam

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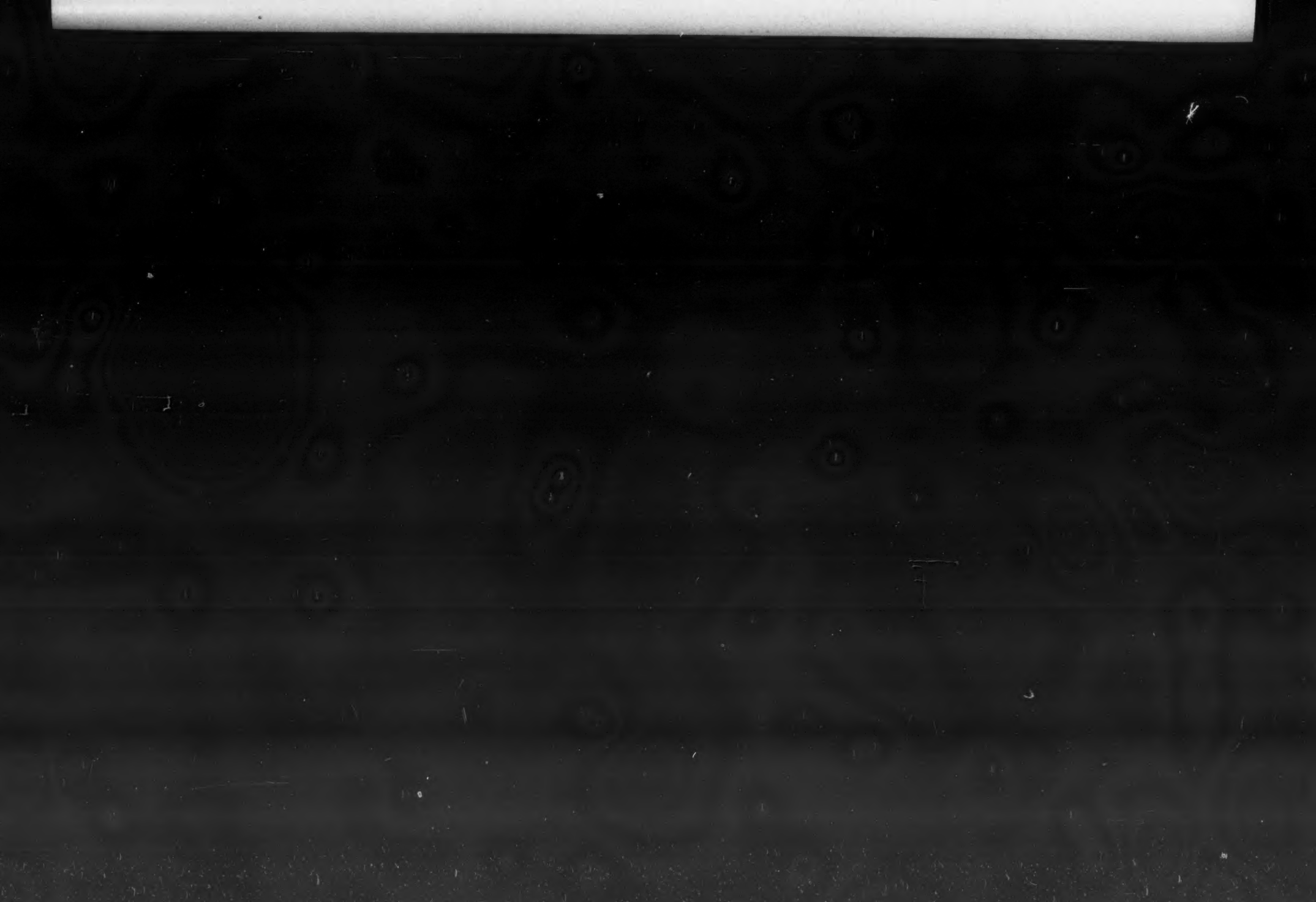

Fouling in Organic Reactors

The potential build-up of insulating "fouling" films at the surface of the fuel elements of an organic cooled reactor has always been a major concern of the organic reactor concept. Should such a build-up take place it would require a derating of the heat transfer capabilities of the core and possibly a complete interruption of the operation of the reactor.

by C. A. TRILLING
(Associate Director, Organic Reactors, Atomics International)

EXPERIMENTAL evidence from the operation of the OMRE, as well as from in- and out-of-pile loops has demonstrated that under certain conditions fouling of heat transfer surfaces can take place. Significant deposits have been observed in unirradiated systems only at temperatures considerably in excess of those presently contemplated for application in out-of-core components of organic reactors. The films observed on all surfaces outside of the high flux regions of the reactor (OMRE piping, heat exchanger and vessels, heat transfer and purification test loops) have always been extremely thin (less than 0·0001 in thick after three years at the OMRE) and have shown every indication of saturation in a short period of time without increasing the susceptibility of these surfaces to the formation of further deposits.

OMRE Experience

The OMRE cermet driver elements consist of plate type fuel elements containing 93% enriched UO_2. The fuel in these plates is 0·02 in thick and consists of 25% UO_2 in stainless steel; 0·005 in of stainless steel cladding are provided on each side of the fuel resulting in an overall plate thickness of 0·03 in. A 0·134 in coolant channel separates the various plates.

Fuel handling at the OMRE is carried out by means of a portable crane. The reactor shelter is opened by removal of its upper section; the reactor vessel head is then taken off with the control rod drives and snubber basket. From then on the hot coolant is exposed to the ambient atmosphere for the extended periods of time required for disconnection of thermocouples, installation and removal of fuel elements, rearrangement of fuel elements and all other operations required for maintenance inside of the reactor vessel. In these circumstances it is impossible to prevent the contamination of the coolant with oxygen and water, and the consequent corrosion of the carbon steel surfaces of the reactor vessel and piping system.

Operation of the first core of the OMRE did not include any precautions for filtering the coolant. Because of mechanical difficulties associated with its self-cleaning feature the small filter originally installed in a by-pass loop never operated satisfactorily. The only control of the quality of the coolant was maintained by distillation in a small batch purification unit operated at the throughput rate required for control of the high boilers in the coolant at a concentration of 30%. This resulted in distillation of the whole inventory of coolant only once in 45 days.

The reactor vessel was never opened during the initial six months of operation of the first core. Information obtained from in-core instrumentation did not indicate any change in the heat transfer characteristics of the fuel elements. The activity of the coolant remained very low and approximately constant during this whole period. Examination of a fuel element at that time revealed a negligible thickness of deposit on its fuel plates. The reactor was then shut down. The reactor vessel remained open for an extended period of time for fuel handling and installation of experimental fuel elements. Upon resumption of operation an immediate build-up of Mn^{56} corrosion product activity was observed. The presence of a high concentration of corrosion products in the coolant was confirmed when the two experimental fuel elements plugged at the inlet of their coolant channels. Though partial melting of the cladding took place on one of these fuel elements, there was no evidence of fouling as defined by deposition of a significant film at the surface of the cladding.

Sintered metal filters were installed in a by-pass system at the OMRE at the start of operation of its second core. Again these filters proved unsatisfactory as they plugged within very short periods of time (less than one hour for the 5 micron unit). The reactor vessel was opened relatively frequently; step increases in coolant activity were always observed following resumption of operation. The temperature at the surface of the OMRE driver elements increased steadily at constant power level pointing out a change in heat transfer conditions. Partial blocking and reduction of coolant flow was indicated in several of the channels.

Hot cell examination of the driven elements revealed appreciable deposits (0·002 in to 0·01 in in thickness) at the surface of the driver element fuel plates with some bridging evident in the coolant channels. Examination of the low enrichment aluminium clad U-Mo test elements on the other hand showed these elements to be almost perfectly clean with just the presence of a thin transparent film through which the original fabrication scratches could clearly be seen. These elements had operated under conditions quite similar to those of the OMRE driver elements in the same coolant.

Analysis and Evaluation of Deposits

Analysis of a multitude of samples of deposits from the OMRE show them to contain 20 to 30% of inorganic material (mostly iron percarbide, $Fe_{2.2}C_2$) as compared with an ash content in the coolant of 100 to 200 ppm. Electron micrographs of samples of deposits show them to consist of inorganic crystallites surrounded by what appears to be a halo of organic material. The particle size is quite small (most particles are smaller than 5 microns with many of them smaller than 1 micron).

Deposits obtained in out-of-pile heat transfer loops have also shown a high inorganic content. The most prevalent inorganic material in these deposits has been iron oxide, Fe_3O_4. Use of Montar 9, a bottoms product from the manufacture of terphenyl, to simulate high boilers in an out-of-pile heat transfer loop at the Naval Research Laboratory has resulted in deposits containing lead introduced with the Montar 9[1]. In the absence of contamination, out-of-pile loops can be operated at temperatures of up to 950 to 1 000°F with no indication of deposits on the heat transfer surfaces.

It is to be noted that similar observations have been made in water reactors. Any contaminants present in the water will concentrate immediately at the surface of the fuel elements as evidenced at the EBWR, in a water in-pile loop at NRU, and in other reactors.

The source of inorganic particulates appears to be the introduction into the coolant of corrosion products from the reactor system. There is a direct correlation between the activity and ash content of the coolant and exposure of the coolant and system to the ambient atmosphere during reactor shutdown. Exposure of the hot organic coolant to oxygen and water vapour results in oxidation of the carbon steel surfaces of the system and introduction of contaminants into the coolant. It is to be noted that the corrosion rate of terphenyl on carbon steel is normally quite low (approximately 0·05 mg/cm² per month at 600°) and is significant only during and immediately after exposure of the hot coolant to the ambient atmosphere.

Organic material is present in the particulates. Most of it is observed at the periphery of the inorganic crystallites, where it has either deposited as a result of nucleation or polymerized as a result of the catalytic activity of iron, iron oxide or carbide. A small amount of entirely organic particulates is also present.

(1) Ewing, C. T., et. al., "Heat Transfer Studies of a Forced Convection Loop with Biphenyl and Biphenyl Polymers," NRL Report 4990, Nov. 1957. also reported in Ind. Eng. Chem., **50**, 895-902 (1958).

This material is probably formed by direct precipitation of insoluble higher molecular weight fractions of the high boiler decomposition products.

Theory of Film Formation

A theory of film formation has been developed which consistently fits all of the experimental observations[2]. It is proposed that surface films are formed by the deposition and permanent binding at heat transfer surfaces of suspended particulate material circulating in the coolant.

The main source of the particulates is the corrosion of the carbon steel system of the reactor by the coolant. This corrosion can be accelerated appreciably by exposure of the coolant to the atmosphere with consequent solution of oxygen and water vapour, and mild oxidation of the coolant. Organic compounds are catalytically polymerized at the surface of the iron-containing inorganic crystallites thus introduced into the coolant. Some of the smaller particles may actually originate directly from the precipitation of the very high molecular weight components of the high boilers, though all the experimental evidence indicates that the contribution from purely organic particles is very small. The concentration of these particles builds up in the coolant until it reaches a steady state value established by the operating characteristics of the system and the various competitive mechanisms of removal (distillation, filtration, settling, film formation).

These particulates circulate in the coolant at concentrations which under unfavourable conditions may amount to 100 to 200 ppm. As a result of diffusion and Brownion motion, they impinge at a high rate on the various surfaces of the system. Typical fluxes of particles incident at the surface of reactor fuel plates have been estimated at 10^6-10^7 particles/cm^{2}s.

The rate of build-up of film on heat transfer surfaces can be expressed as the integral over the whole range of particles present of the product of the flux of particles impinging on the surface and a sticking probability, or cross-section for permanent attachment to this surface. (Under OMRE conditions, this sticking probability has been estimated from experimental data to amount to 10^{-4} to 10^{-3} particles which remain permanently attached to the surface for each particle which comes into contact with this surface.)

A surface deposit can become a permanent film only if there exists some degree of chemical bonding to the surface and within the material comprising the deposit. In a coolant system, a particle contacting a surface will not remain permanently attached unless chemical linkages are established which are stronger than the mechanical forces, such as those caused by fluid flow, vibration, thermal stresses, and gravity. The sticking probability, S, is the probability that, for a particle contacting the surface, sufficient chemical bonds will be established to ensure that the particle is retained as a part of a permanent film, and that it is not swept away again in the coolant stream.

Obviously, S will depend upon the chemical nature of the exterior of the particle and of the exterior of the solid surface contacted by the particle. If chemical linkages can be established, the process will certainly be temperature dependent; and, for conventional situations, the value of S increases exponentially with the temperature at the surface.

Within a reactor core at the temperatures under consideration (750-850°F), the temperature measured at the solid surface is not likely to be the primary factor affecting S. This has been confirmed by the lack of noticeable differences in the thickness of deposits throughout the various regions of the OMRE driver element fuel plates, which see a whole spectrum of temperatures from bulk coolant to hot spot.

The environment of nuclear radiation artificially creates local instances of temperature extremes. Interaction of radiation with the atoms in the vicinity of the particle-surface interface will be capable of establishing chemical linkages which otherwise would be impossibly slow to form. The presence of this radiolytic effect has been observed in both water and organic cooled reactor systems. In evaluating the importance of S in the formation of films, the great difference between the in-pile and out-of-pile situations must be noted.

(2) Parkins, W. E., "Surface Film Formation in Reactor Systems," NAA-SR-6048, January, 1961.

Another important influence of the value of S in reactor cores can be that of an increased residence time of a particle at the surface, due to electrostatic forces resulting from the beta electron current. Obviously, the magnitude of this effect will depend upon the current density of beta electrons flowing into the coolant. This, in turn, is dependent upon such quantities as the fissioning rate in the fuel, the composition of the cladding, and the thickness of the coolant channel. There is also evidence that the effect can be dependent upon the electrical resistivity characteristics of the coolant and of any formed surface film since these quantities control the electrical discharge rate of the coolant.

The flow velocity of the coolant is also important in determining S. The velocity should have essentially no influence on the probability that a particle circulating with the coolant will come in contact with some given surface, but it can affect the residence time of that particle at the surface, once contact has been established. Any particle in contact with a surface is subjected to a force by the fluid flowing in the laminar layer, tending to roll the particle along. The higher the bulk coolant velocity, the greater this force will be, since the velocities in the laminar layer increase accordingly. Locations where turbulence is present should result in a decreased value of S, an effect similar to that of increasing the velocity in the laminar layer.

It will also be apparent that S should be smaller for large particles than for small particles, since the shearing force applied by the fluid, which tends to move the particle along the surface, is larger. The particle not only presents a larger profile, but its extremity which is away from the solid surface is in the vicinity of more rapidly flowing liquid. For any particular situation, the shape of the particle, and the microscopic irregularities which the surface presents, can influence the residence time. It is nevertheless helpful to think in terms of a value of S, which is the average probability that a particle which contacts the surface once will become permanently bonded there.

The effect of the nature of the heat transfer surface at these temperatures appears very small. Though the sticking probability on aluminium or APM seems considerably lower than that on carbon or stainless steel under conditions of low temperature and absence of radiation field, there appears to be no difference in the behaviour of these elements at high temperatures and in a radiation field.

Solution of Fouling Problem in Organic Power Reactors

On the basis of the theory presented, it is expected that formation of film deposits at the surface of organic power reactor fuel elements can be eliminated, or at least minimized by:—

1. Minimizing of the source of the insoluble matter by limiting the introduction of corrosion products into the coolant (by minimizing contact of the hot coolant or inside walls of the reactor system with the atmosphere, and in-leakage of water into the coolant) and removing the higher molecular weight fraction of the high boilers, potential precursors of organic particles, as fast as it is formed (by distillation or adsorption).
2. Removing whatever insoluble particulates have been allowed to form. This removal can be accomplished by filtration, or by distillation.
3. Minimizing the residence time of the particles at the surface of the fuel elements by maintaining coolant velocities as high as practical, eliminating stagnation points, and also minimizing the electrostatic effects at these surfaces.

The present evaluation of the fouling problem in organic reactors has led to the development of a self-consistent theory which fits and explains all the experimental data obtained from the operation of the OMRE and of high temperature out-of-pile organic loops. An important problem which remains to be solved is that of successful control of the insoluble matter content of organic coolants. Major emphasis is presently being placed on the use of distillation, filtration and adsorption techniques. It is expected that operating experience with the third core of the OMRE will provide at an early date successful demonstration of the solution to the fouling problem.

Fabrication Development of APM Fuel Elements for Organic Cooled Reactors

by E. G. KENDALL
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and
G. V. ALM, W. H. FRISKE, M. H. BINSTOCK, B. N. BRIGGS, B. GRADLE
(*Process Development Group, Fuels & Materials Department, Atomics International*)

Strength at high temperature, high thermal conductivity, low neutron absorption and good corrosion resistance make APM alloys especially suitable for cladding OMCR fuel elements. Atomics International is developing an APM alloy, Alcoa M257, as a fuel cladding for ceramic fuels such as UO_2 or UC.

ALUMINIUM powder metallurgy (APM) products are being developed by Atomics International for application in organic moderated and cooled reactor (OMCR) systems. APM alloys are superior to conventional wrought aluminium alloys in that they possess good high temperature strength which is retained after prolonged periods of heating. This high temperature strength, along with the properties of high thermal conductivity, low neutron absorption and excellent corrosion resistance in organic coolants, make APM alloys especially applicable as cladding and structural materials for OMCR fuel elements. M257, an APM alloy produced by Alcoa, is being developed as a fuel cladding for ceramic fuels such as UO_2 or UC which offer the potential of high fuel burn-up and low fuel cycle costs. OMCR fuel elements utilizing these ceramic fuels clad with M257 can be operated as structural cladding at temperatures up to 900°F, some 200 to 300°F higher than wrought aluminium clad elements.

Fuel elements consisting of UO_2 pellets contained in M257 fuel tubes are being fabricated by AI for testing in OMRE. The fuel tubes are forward extruded using the impact extrusion process. Typical tubes are 0·305 in i.d. with 0·030-in walls, and have eight longitudinal fins, 0·030 in wide by 0·086 in high. For a typical element, the tubes are extruded in 5-ft lengths with a tolerance of ±0·003 in for both wall thickness and diameter. In other fabrication development efforts, however, tubes with 0·015-in walls and 10 longitudinal fins have been impact extruded in lengths up to 14 ft. Prior to loading the tubes with the UO_2 fuel, the tubes are further processed by twisting to give a uniform spiral of 45°/ft. End closures in the fuel tubes are made by a eutectic diffusion bonding technique developed at AI.

A structural application for APM alloys in OMCR is the process tube, or fuel box, which contains the fuel tubes and directs the coolant flow. Under typical design conditions, this box would need to withstand internal pressures of 16 psi at velocities up to 30 ft/s and temperatures up to 700°F. Stainless steel has been employed in the past but it can be expected that boxes for future OMRE elements and for OMCR power reactor designs will use these alloys producing a considerable improvement in neutron economy.

PROPERTIES

Two types of APM alloy are available commercially from Alcoa:

(a) A dispersion of Al_2O_3 in a matrix of aluminium and

(b) A pre-alloyed atomized powder, utilizing insoluble intermetallic compounds as the dispersion strengthening media.

Alloy M257, the alloy being evaluated by AI, contains about 5% of Al_2O_3, while other alloys made by Alcoa are M470 and M430 containing 10% and 14% Al_2O_3 respectively. A recent addition, M583 (designed as a replacement for M257) is being produced according to a revised powder preparation method, to yield a product with a lower impurity content. Future fuel element fabrication effort is expected to concentrate solely on this M583 alloy. Alloy M486, one of the currently available pre-alloyed powder products, has the nominal composition of 7·8% Fe with 0.2% each of Cr, Ti, Zr and V, and contains approximately 0.5% Al_2O_3 as an impurity. Others include M457 and M643, both containing Fe and Ni as alloy additions. They are being developed because of their corrosion resistance to high temperature water or steam.

The mechanical properties of APM alloy M257, along with those of the other alloys mentioned above, have been published[1]. These data include tensile properties at temperatures up to 1 000°F, creep-rupture properties up to 900°F, and creep properties up to 600°F. The objectives of the mechanical property studies undertaken in the programme at AI were to confirm published data, to develop further creep and creep-rupture properties in the temperature range above 600°F, and to determine the effect, if any, of fabrication history on

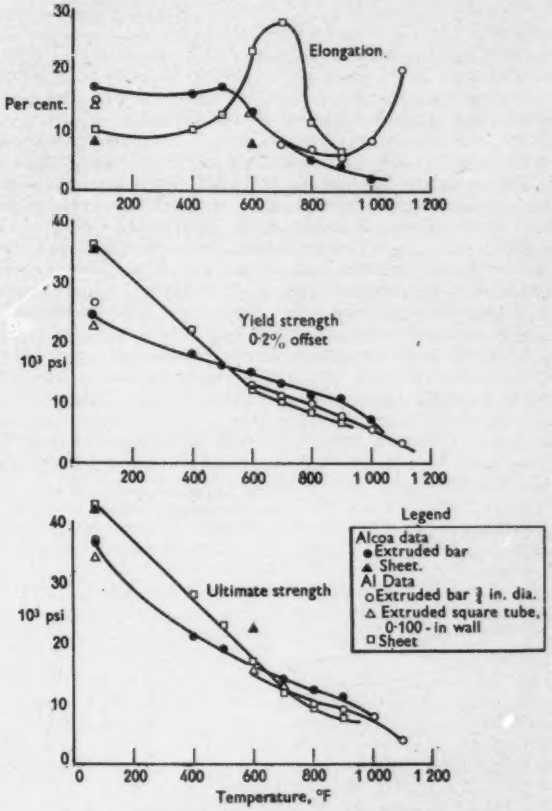


Fig. 1.—Tensile properties of APM alloy M257.

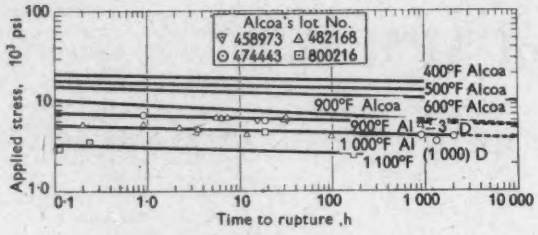


Fig. 2.—Creep-rupture strength of M257 (as-extruded).

mechanical properties[2, 3]. The principal alloy to be investigated was M257 as it was most readily available and possessed the most desirable combination of ductility and strength at temperatures above 800°F.

The average tensile properties of M257 for temperatures up to 900°F are depicted in Fig. 1. The values plotted include data for M257 in the as-extruded conditions and for as-rolled sheet. Previously published values are also plotted for reference. Good agreement was obtained for room temperature tensile properties for both conditions. At temperatures above 600°F, the ultimate and yield strength values determined in this investigation were some 10 to 15% lower than those claimed for M257 in the as-extruded condition; conversely, however, it was shown that ductility (elongation) increased at temperatures above 900°F. This improvement in ductility is believed to be advantageous for fuel rod applications and more than compensates for the lower tensile strength.

M257 in the as-rolled sheet condition was found to have slightly higher tensile strength and lower ductility than extruded material at temperatures up to about 600°F. Above 600°F, the as-rolled sheet tensile strength falls slightly below the as-extruded strength. Also, the ductility of sheet was shown to increase markedly, peaking at about 28% elongation at 700°F.

Creep tests were conducted at 900°, 1 000° and 1 100°F. A plot of creep-rupture strength is shown in Fig. 2. The specimens tested represented four different lots of extruded stock and the data indicate that there is no significant lot-to-lot variation in creep-rupture strength. Previously published data are also plotted for reference. As found with the tensile properties of M257, the data produced by AI show a small but significant decrease in the creep-rupture strength from the listed values.

The creep characteristics of Al-Al_2O_3 alloys are unique in that most of the deformation occurs in the primary creep stage, with only negligible secondary creep until rupture. APM alloy M486, a pre-alloyed powder rather than a mixture of Al_2O_3 in Al, creeps in much the same manner as conventional ductile metals, with the expected primary, secondary and tertiary stages of creep. However, the creep strength of M486 deteriorates rapidly at temperatures above 800°F.

Tensile and creep tests have shown that elevated temperature strength properties of M257 are lowered somewhat by cold working as induced by cold rolling and swaging. The effect of cold working is nevertheless small, as shown by the tensile data of Fig. 1 and the creep-rupture data of Fig. 3. All the APM alloys are used in the as-fabricated condition as they do not respond to ageing, annealing or solution heat treatments.

The effects of irradiation on tensile and impact properties of M257 and M486 have been investigated and differences between irradiated and unirradiated properties found to be insignificant[4].

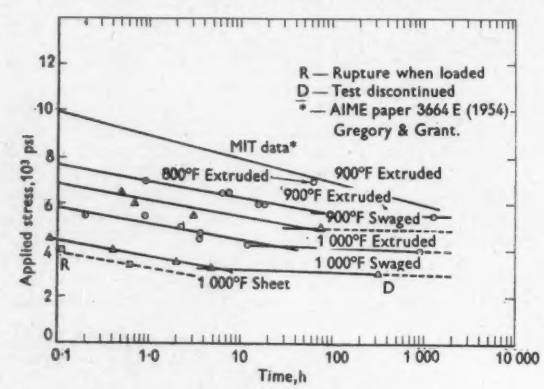


Fig. 3.—Creep-rupture data for M257.

FABRICATION

APM alloys can be fabricated to many of the common mill shapes by conventional forging, rolling or extrusion processes. In general, the fabrication characteristics of M257 were found to be very similar to those of type 7075 aluminium alloy. One of the principal shapes used by AI is a longitudinally finned

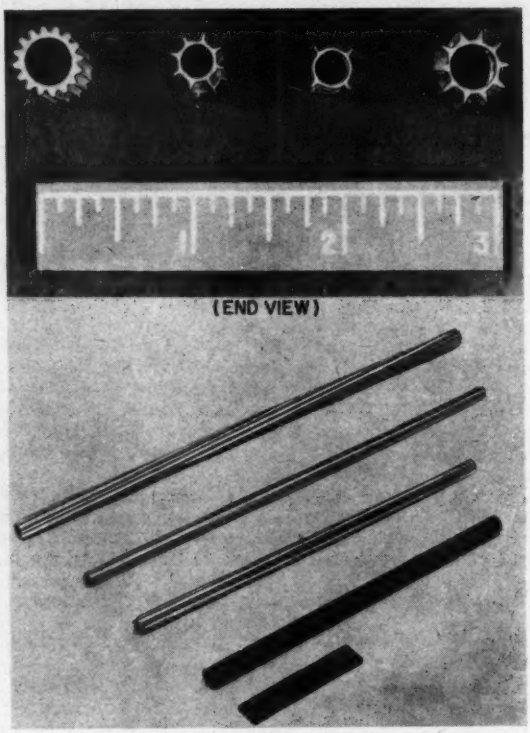


Fig. 4.—Tubular shapes extruded from APM257; (top) end view, (below) side view.

tube which serves as a fuel tube for containing UO_2 pellets. Finned tubes of various configurations and sizes made to date, shown in Fig. 4, have been produced by forward extrusion techniques. The most successful has been hot impact extrusion at 800-900°F. By this process, finned tubing of excellent quality and dimensional control has been produced from M257. An eight-fin design configuration with dimensions and tolerances is shown in Fig. 5. Although tubes of this configuration are presently extruded in lengths of about 5 ft to attain the closest dimensional control possible, lengths of up to 14 ft have been produced by impact extrusion.

Based upon a pilot run of 1 000 ft of tubing, dimensional tolerances consistently obtainable in these lengths are given in Table 1:

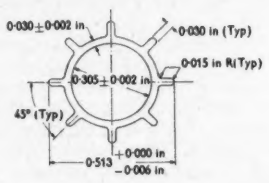


Fig. 5.—Eight-fin M257 fuel tube.

Table 1.—Dimensional tolerances on hot impact extruded finned tubes

Parameter	Dimension
O.d. (on opposite fins)	0·505 ± ·003 in
I.d.	0·305 ± ·002 in
Fin height	0·075 ± ·002 in
Fin base thickness	0·030 ± ·003 in
Wall thickness	0·030 ± ·0025 in

Ten and 12 fin variations of the same size (0·30 in i.d. × 0·030 in wall) tubing have also been successfully extruded with good indications of comparable dimensional control. Extrusion experience has shown that acceptable quality tubing can be expected in wall thicknesses as low as 0·015 in.

Inspection

Various tests, both destructive and non-destructive, have been used to establish reasonable confidence in extruded M257 finned tubes. As cold forming operations after extrusion have shown evidence of lowering the mechanical properties (especially severe tube drawing), only as-extruded tubing is recommended for reactor fuel cladding.

Finned tubing is inspected for cracks, seams, slivers, blisters, burns, die marks, or other injurious imperfections which are known to affect the physical properties of the tubing. Surfaces must be clear to fluorescent penetrant inspection.

The M257 tubing has conformed to the composition and impurity levels shown in Table 2.

Table 2.—Principal properties of M251 tubing

Composition:		
Aluminium		Remainder
Aluminium oxide		5·0–7·0
Iron		0·70 max.
Silicon		0·30 max.
Boron		0·001 max.
Cadmium		0·003 max.
Other impurities, total		0·015 max.
Individual		0·005 max.
Minimum tensile properties of billet or tubing:		
	65°F	900°F*
Ultimate tensile strength	32,000 psi	8,000 psi
Yield strength, 0·2% offset	19,000 psi	6,500 psi
Elongation in 2 in (%)	10–18	4

* After heating for one hour at temperature.

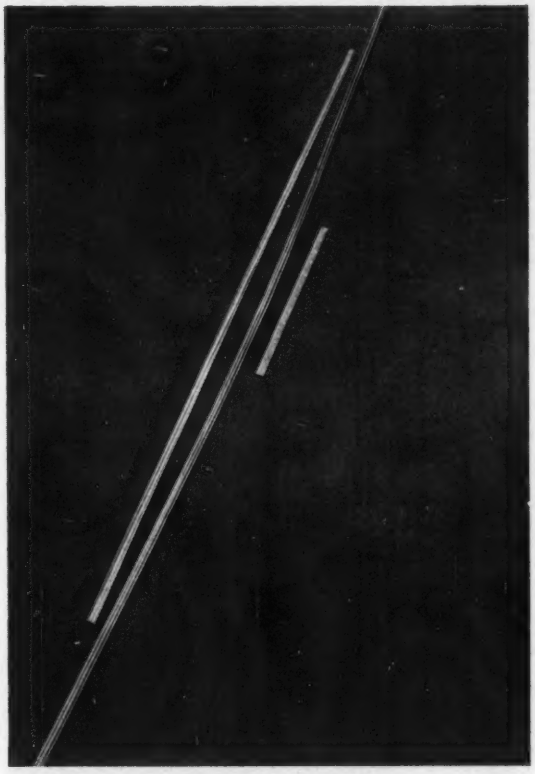


Fig. 6.—M257 tubes as-extruded and after straightening, spiralling and cleaning.

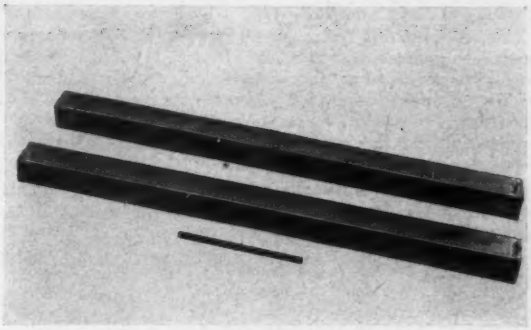


Fig. 7.—Extruded square boxes of M257 and M486.

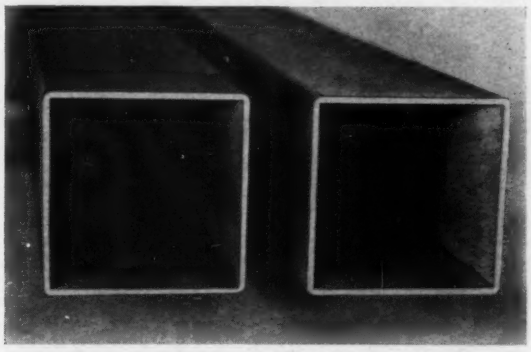


Fig. 8.—Cross-section view of square box extrusion.

Each length of tubing must be leak-tight when tested by a mass spectrometer leak detector which will detect a leak rate of 1×10^{-9} std. cm³/s of helium. Testing is performed at room temperature and 900°F at a pressure differential of one atmosphere for a period of at least five minutes. Borescope inspection of surfaces and isostatic internal pressure tests (3 000 psig for eight-fin, 0·030-in wall × 0·305-in i.d. tubes) complete the incoming inspection of as-extruded tubing. Tubes which pass as-extruded inspections are stretch-straightened, and spiralled in one operation; end cropping and chemical cleaning are then performed (Fig. 6).

If tubing is to be used for in-pile experiments a more thorough pre-fuel loading inspection is made. This inspection is similar to previous inspections except that a complete dimensional profile of each tube is made with all dimensions being recorded. A fin twist of 45·0 ± 5°/ft is required and inspection is made at this time to assure conformance. Complete dimensions are taken at 4-in intervals along the entire length of the fuel tube. Such data is useful in ascertaining fuel tube dimensional changes which may occur during irradiation and burn-up tests. Air gauge probes are used for tube i.d. measurements while specially constructed inspection fixtures are employed to measure tube exterior profiles.

Straightening and Twisting

Twisting the tubing to produce the helical fin configuration is performed during the stretch-straightening operation. This operation consists of clamping the tube at each end in the rotatable grips of a modified tensile machine and exerting a load slightly exceeding the yield strength of the metal. While this load is maintained, the end grips are equally rotated. A rotation of double the 45° per ft of tubing is required due to

springback. The stretching load is released before twisting forces are relaxed. The described procedure yields tubing with overall straightness of ±0·005 in TIR in 5 ft lengths. A slight and uniform reduction in tube dimensions (0·0005 in max.) also occurs. Thermal cycling of processed tubing to 1 000°F has been shown to produce no relaxation in fin twist.

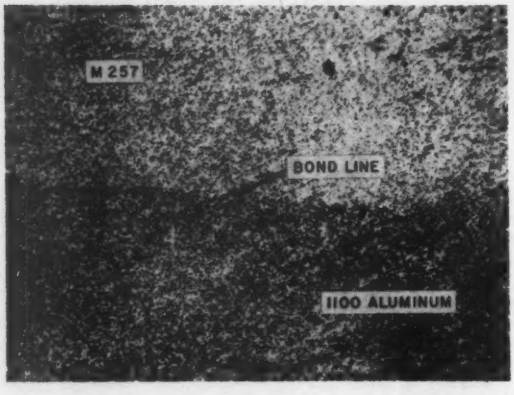
Fuel Boxes

APM alloys are also being developed for structural applications in organic reactors. One of these applications is as a pressure tube, or fuel box, which contains the fuel tube and directs the coolant flow. In recent development efforts, square tubes, 2·950±0·005 in outside dimensions, with walls 0·100±0·005 in thick, have been successfully extruded in 48-in lengths from two APM alloys, M257 and M486. Typical tubes are shown in Figs. 7 and 8. Tests have shown that these square tubes possess the necessary strength and dimensional stability for this application.

DIFFUSION BONDING

APM products do not lend themselves to joining by conventional techniques such as inert gas arc welding. Any fusion by melting usually segregates the oxide particles from the matrix aluminium. A technique for obtaining helium leak-tight end closures on M257 tubes was developed using a eutectic diffusion bonding process.

Metals including Ag, Cu, Sn, Zn and Al-12 w/o Si, which all form a eutectic with aluminium at least 100°F below the melting point were investigated. Preliminary trials were made using both vacuum deposited and electroplated materials where appropriate. Metallographic examination revealed bonds were attained using Ag, Cu, and Sn; however, Ag always exhibited more total diffusion and yielded bonds free of contamination.



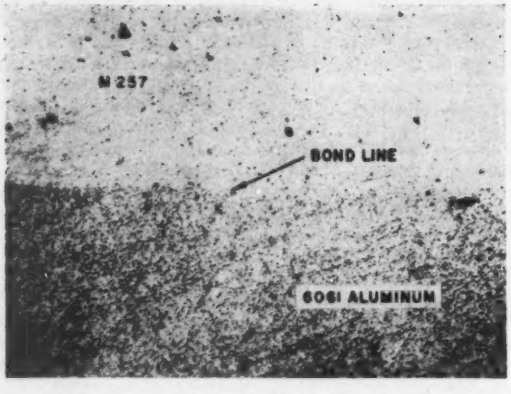


Fig. 9.—Microstructure of eutectic diffusion bonds of M257-1100 Al and M257-6061 Al.

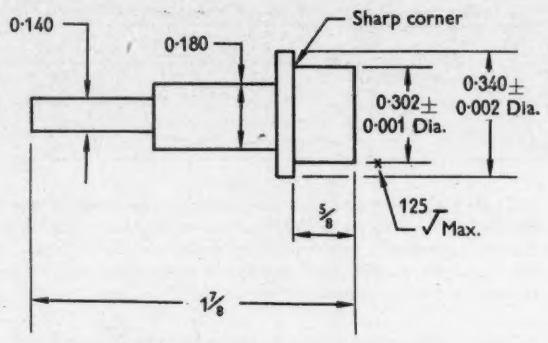
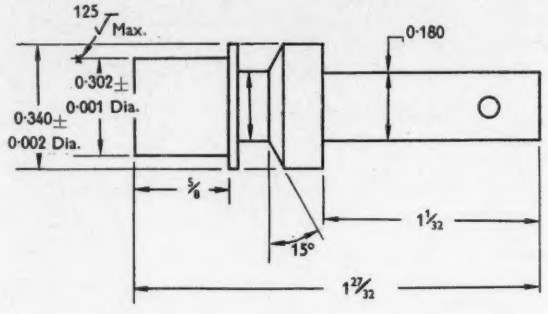


Fig. 10.—Design of top and bottom end plugs.



Bonding has been achieved utilizing M257, 1100, and 6061 Al alloys for end plug material. The 1100 and 6061 Al alloys allow the use of much lower bonding pressure and for this reason only have been selected in preference to the M257. Microstructures of typical bonds are shown in Fig. 9.

In preparation for the bonding operation, straightened and twisted tubing is end cropped, machined to a final length and fins removed $\frac{1}{4}$-$\frac{1}{2}$ in distance from each end. Tubing and end plugs are then vapour degreased in trichlorethylene and alkali cleaned using a bath of Oakite 160 in water followed by a nitric acid pickle. It has been determined that 0·0003 in of metal surface is removed during the cleaning cycle which is, in turn, partially compensated for by the silver plate.

Machined dimensions of top and bottom end plugs used for test elements to be irradiated in OMRE are shown in Fig. 10. A 0·04 in diameter hole, extending through the top end plug, was formerly used to evacuate the tube and back-fill with helium

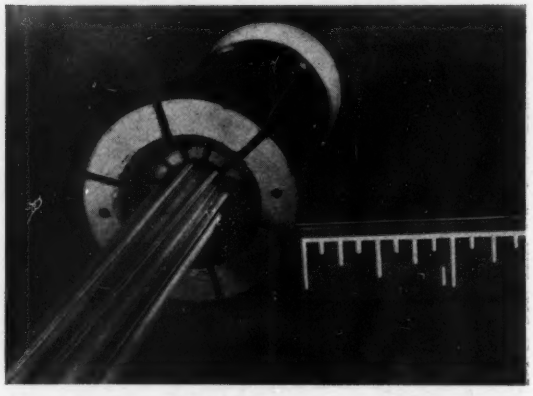


Fig. 11.—Six-segment collet die for bonding.

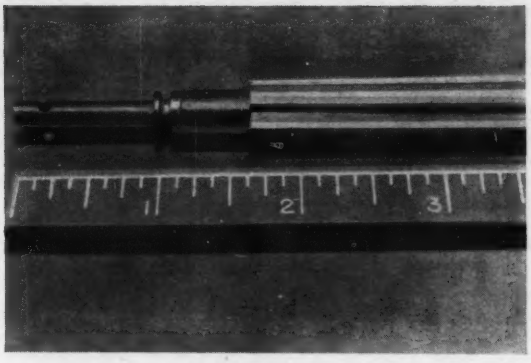


Fig. 12.—Typical fuel tube end closure.

subsequent to bonding of both end plugs. This method was required when bonding was done in air; however, recent results indicate the desirability of inert atmosphere bonding within a glove box. End plugs are cleaned immediately prior to a 0·0001 in thick silver electroplate. The surface of the plug and tubing are then brought into intimate contact using a pressure of 5 000 psi exerted by a pneumatically loaded collet die, seen in Fig. 11, that applies uniform radial pressure. Induction heating is used to heat the restraining die as well as the components to be bonded. Sufficient heat is applied to reach the eutectic melting temperature of silver and aluminium (1 050°F). Localized eutectic melting occurs at the interfaces to establish a bond between the end plug and tube. Continued heating causes metal of eutectic composition to diffuse into the end plug and tube matrices.

This process has been put into practice for the production of M257 tube end closures of the type shown in Fig. 12. End closures obtained in this manner using 0·030 in wall tubing have remained helium leak-tight after thermal cycling between 70 and 900°F for 30 min intervals and internal pressure tests of 1 500 psig at 900°F and 3 000 psig at 70°F; in addition they have always proved stronger than the tubing itself when burst

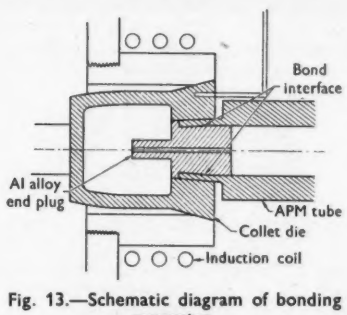


Fig. 13.—Schematic diagram of bonding apparatus.

tested at 750°F. A schematic diagram and photograph of the bonding equipment arrangements are shown in Figs. 13 and 14 respectively. The apparatus consists of the six-segment collet-type die, a matching tapered die sleeve, a pneumatic cylinder loading device, temperature sensing thermocouples, and an induction coil for heating.

The microstructure of a well-established bond shows complete grain continuity extending across the interface with no observable silver or intermediate diffusion zones remaining.

Metallographic examination of bonds indicate reproducibility irrespective of whether bonding is accomplished in air or inert atmosphere, but indications are that inert atmosphere bonding provides improvement in bond strength and reliability due to less danger of oxide formation at the interfaces. Thus, the arrangement as shown in Fig. 14 has since been incorporated inside a glove box.

Fuel Element Fabrication

Based upon a prototype fuel element design for a 50 MW(e) improved cycle OMCR, test elements 3 ft long have been fabricated for irradiation in OMRE. A test element, shown in Fig. 15, consists of a 25-rod tube bundle of UO_2 pellets within M257 alloy finned tube cladding. A 25-rod bundle was selected because of its ability to be inserted into existing fuel element positions in OMRE. The fuel tubes are spaced in a 5 × 5 array by means of stainless steel end spacers. After bundling and

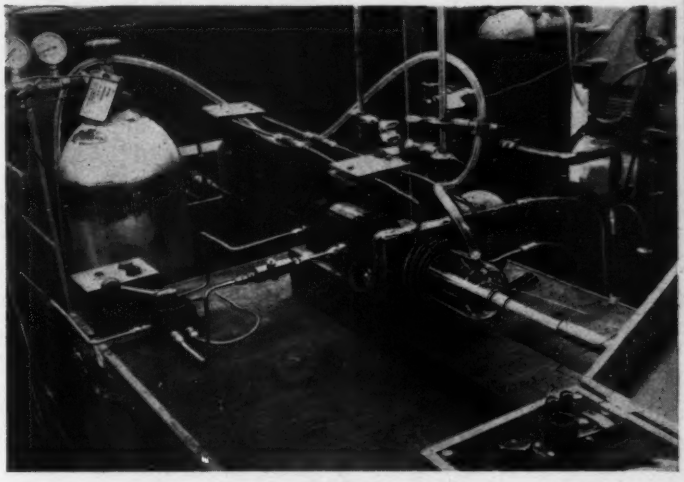


Fig. 14.—Photograph of bonding apparatus.

attachment of thermocouples, the assembly is inserted into a stainless steel box and stainless steel fixtures are welded to the ends. An exploded view of the complete element can be seen in Fig. 16.

Sintered and ground UO_2 pellets, 94% theoretical density, are being used as the fuel material. An annulus of 0·0025-0·003 in has been provided between the UO_2 pellets and the APM tube wall and pellets have been air gauge inspected, individually, prior to loading.

After bonding the bottom end closure, the required length (about 32 in) of weighed fuel pellets are manually loaded into the fuel tube together with end spacers and springs. Stainless steel tube end spacers are used to provide space for accumulation of fission gases. Dished-out molybdenum spacers adjacent to each end pellet are employed as a precaution to ensure that centre melting of UO_2 pellets does not cause melting of adjacent metal components. An Inconel spring is used to hold the fuel pellet loading stationary during storage and handling. In this way expansion of pellets can be accommodated and separation of pellets during handling can be prevented.

Sealed rods containing fuel and helium at a pressure of 1 atm which pass thermal cycling and hot helium leak tests are ready for final assembly into the multi-rod fuel element. Helium filling is accomplished, either by bonding in a helium filled glove-box or by evacuating and back filling with helium through the hole drilled in the top end plugs; fusion welding is then subsequently employed to seal the hole.

In each prototype test element thermocouples are attached to fuel rods as well as being located in the coolant channels to monitor both cladding surface and coolant temperatures. In some cases flow and fission gas pressure measuring devices have been incorporated.

Fuel rods are positioned in end support plates, the identity and position of each rod being recorded; the rods are then locked into position with bottom end plug locking pins of Type 304 stainless steel. The fuel bundle is inserted into the Type 304 s.s. fuel box and the sides of fuel spacer support plates aligned to pre-drilled holes before plug welding to the box. Thermocouple leads and other conduits are drawn

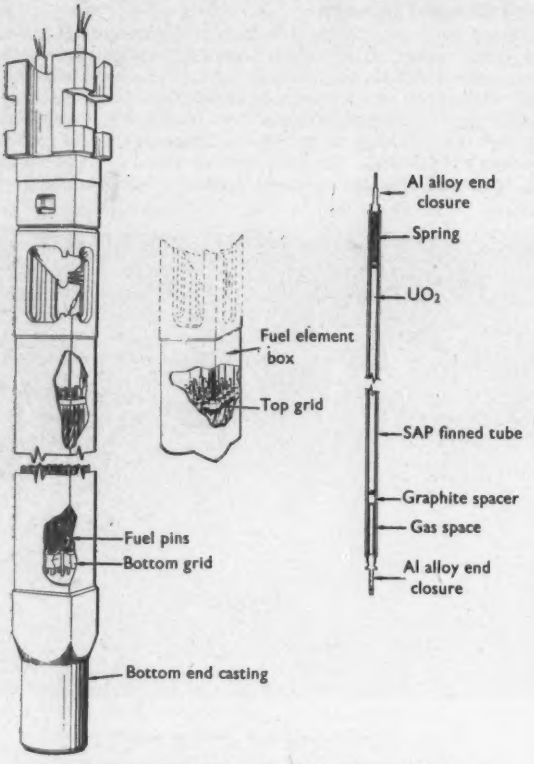


Fig. 15.—APM-UO_2 irradiation test element for OMRE (design).

together through the head extension diverter assembly and coolant channel thermocouples are also attached. The fuel element end pieces, made of machined Type 304 s.s., are then aligned and welded to the fuel section in a specially constructed rotating alignment fixture. Thermocouple splices and connections are made with the lead-out thermocouple wires being housed in a Type 304 s.s process tube welded to the head extension.

Use has been made of the APM tube fins to attach 0·020 in o.d. sheathed thermocouples (the chromel-alumel wires are 0·003 in diameter). This is accomplished by splitting the fin with a 0·010 in thick milling cutter, laying the wire in the formed groove, and then folding over the fins to securely hold the wire in place. This method has been found to be superior in all respects to other attachment techniques such as tack welding or brazing of bare wires directly to the tube surface. In addition, this method produces no deleterious metallurgical effects on the M257 cladding.

Because of the high electrical resistance of 0·003 in diameter chromel-alumel thermocouple wires it has been found necessary to make a splice of this wire for lead-out purposes with 0·010 in wire housed in 0·063 in stainless steel sheathing. Splicing by silver brazing is made so as to yield a completely leak-tight junction.

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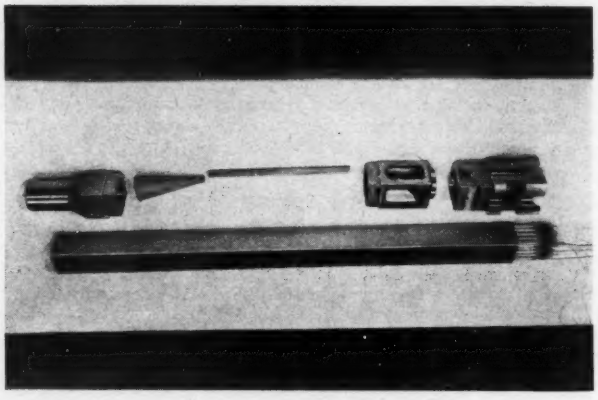


Fig. 16.—APM-UO_2 irradiation test element for OMRE (as-fabricated).

OMR Projects in . . . Spain

IN Spain the Junta de Energia Nuclear is working on a research and development programme which has the construction of a 30MW(e) heavy water moderated, organic cooled, natural uranium fuelled reactor (Don) as its objective. The programme is being undertaken in collaboration with Atomics International and for the first stage a heat transfer rig and exponential experiment have been built. The latter is initially being used with uranium oxide fuel elements. Later these will be replaced with uranium carbide, the principal fuel to be used in Don. Some of the fuel will be enriched.

The heat transfer and exponential tests are expected to be completed by some time in the middle of next year.

A decision as to whether Don, which will be purely experimental, will be built, will depend on whether sanction for foreign expenditure is given. Both small BWR and PWR plants have been studied and there are proposals for 200-250 MW stations, the latter being well supported by industry. In view of the country's financial situation there would seem to be little chance of all the projects being taken up, except with outside help.

In spite of the attraction of the Don project, in view of the Orgel and Canadian programmes, it is still debatable whether it is a worthwhile plant with which to go ahead.

. . . Canada

IT is reported from Canada that the AECL organic programme is progressing favourably. No details of the present state of the programme are available, however, as apparently there are policy changes to be made. These materially affect the organic cooled, heavy water moderated reactor experiment (OCDRE), the studies for which are being conducted for the AECL by Canadian General Electric. An evaluation of the progress of these studies is expected to be ready early next year, when rephasing decisions will be finalized.

The OCDR concept was first investigated by CGE in 1957. So impressed were they by the preliminary results that the following year they undertook a detailed design and cost study for a 150 MW OCDR plant. On the basis of an estimated net station efficiency of 32% they claimed a capital cost of under $300/kW installed and fuelling costs of approximately 1·5 mill/kWh at 5 000 MWd/t burn-up. Coolant make-up at the rate of 40 kg/h would add, they estimated, a further 0·2 mill/kWh to the power costs.

These results confirmed the earlier impressions of the attractiveness of the system and an agreement was reached with AECL for the establishment of an organic-cooled reactor programme, leading to the construction of a 35 MW(th) reactor experiment.

The Metallurgy of Beryllium

Under the sponsorship of the Institute of Metals an International Conference on the Metallurgy of Beryllium was held in London, October 16-18, 1961. Some 70 papers were presented under four main headings—mechanical and physical properties, beryllium in reactors, beryllium in aircraft, and metal preparation and fabrication. This article summarizes the main findings and conclusions described in each session.

A CHARACTERISTIC of beryllium—and one which presents a major problem—is brittleness, and in the session devoted to the mechanical and physical properties of the metal this feature was prominent. The subject was dealt with from three aspects—the nature of the fracture process at low temperatures, the brittle/ductile transition which occurs around 200°C, and the ductility minimum at about 600°C.

There is some measure of agreement on the mechanism of fracture at low temperatures; the primary mode of failure in beryllium, basal cleavage, has been analysed and a sequence of events leading to it proposed. Basal slip is the primary mode of deformation (Fig. 1), the critical resolved shear stress being one-fifth that for prismatic $(10\bar{1}0)$ slip and it is this restriction to one slip system at low temperatures that gives rise to lattice distortion. The basal planes bend under plastic deformation but local constraints lead to the formation of bend planes, i.e., a series of sharp discontinuities instead of a continuously bent lattice. Further deformation leads to splitting of the bend plane and the formation of basal cracks. Electron microscope studies have revealed the presence on the $(1\bar{2}10)$ plane of high density dislocation boundaries which are probably the so-called "bend planes" (Fig. 2).

The electron microscope has also shown that commercially pure beryllium contains innumerable small precipitate particles which hinder dislocation movement and may contribute to raising the yield stress above the cleavage stress for the most favourably oriented fracture plane. In confirmation of the influence of impurities various authors have reported the results of tests on single crystals of zone refined material. These indicate that the critical resolved shear stress for basal slip and prismatic slip decreases as the impurity content is lowered.

The transition fracture from brittle to ductile which occurs within a narrow temperature band around 200°C (Fig. 3) has also been the subject of considerable study. Experimental evidence indicates that refinement of the grain size lowers the transition temperature and results in a general improvement in properties over a range from room temperature to 600°C. The experimental data, however, still seem too limited to permit a critical assessment to be made of the various theoretical models proposed for the brittle/ductile transition in beryllium.

Among the more unusual features of beryllium is the minimum which hot-worked material shows in the temperature-ductility relationship at 600°C. Such behaviour could be explained by a precipitation reaction, but until recently conclusive evidence has not been available. From the papers presented at this conference, particularly by the AWRE,

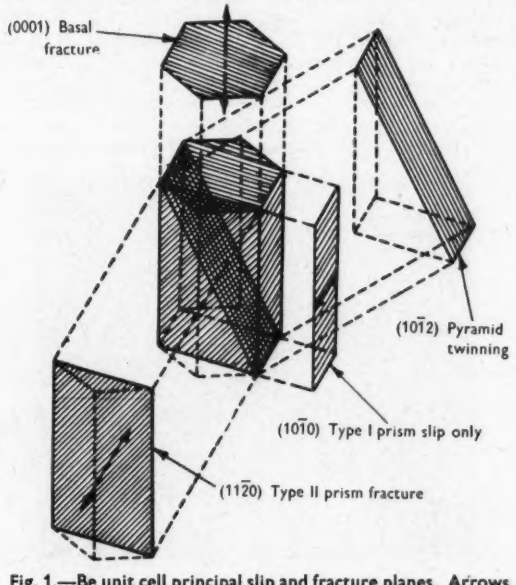


Fig. 1.—Be unit cell principal slip and fracture planes. Arrows indicate direction of slip or fracture. Only significant movements are considered.

Fig. 2.—Dislocations and fine precipitates in Be crystal of commercial purity. Arrows point to dislocations pinned by precipitates. The dislocation array of high density is probably a "bend plane."

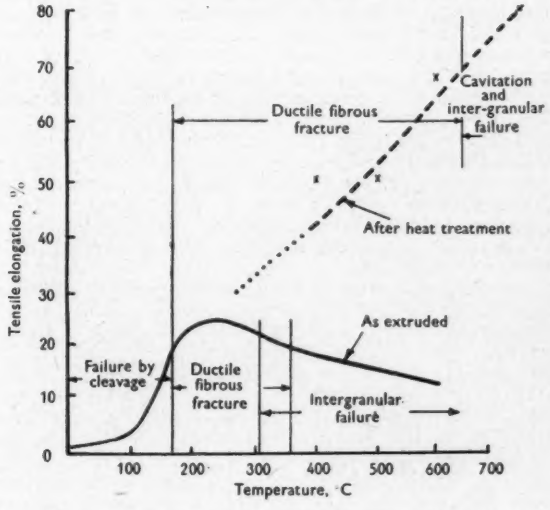


Fig. 3.—Effect of heat treatment on ductility of extruded cast pebble Be

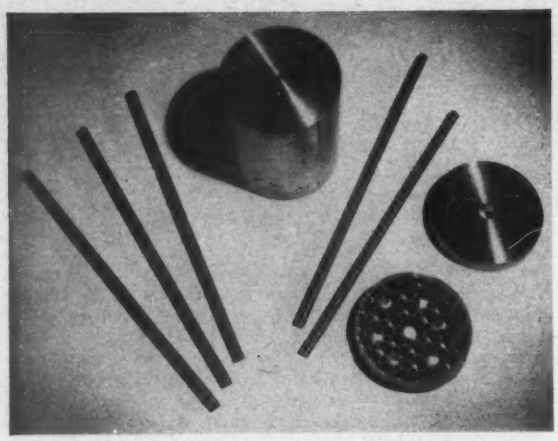


Fig. 4.—Be wrought and machined products (machined plate by Sir W. G. Armstrong Whitworth Aircraft, Ltd.).

Aldermaston, it now seems clear that the ductility minimum in commercial purity beryllium is due to a metastable, aged condition, and that a marked improvement in the ductility can be achieved on overageing the material by prolonged heating at temperatures of 600°C and above.

The iron content of the beryllium seems to be a significant factor in controlling the mechanical properties. The tensile strength increases with iron content over the range 0·04-0·4 wt% Fe as does the speed of overageing. Maximum ductility in the overaged condition, however, appears to reach an optimum at about 0·15 wt% Fe. Regrettably, the purest commercial grade of material currently available (0·04 wt% Fe) seems to have the worst possible iron content; if it were higher, overageing could take place more rapidly and better mechanical properties would obtain; if it were lower, precipitation ageing might not occur. The exact nature of most precipitating phases still remains somewhat obscure: iron, aluminium, silicon, chromium, manganese and nickel have all been detected by electron microbeam probe studies, but some authors, perhaps wisely, simply label microconstituents as A, B, C, etc.

It appears that further work on beryllium of extreme purity is desirable to provide basic data for comparative purposes.

Beryllium in Reactors

For several years now beryllium has been one of the major contenders as a canning material for the Advanced Gas-cooled Reactor (AGR). Recently, however, it has been regarded less favourably in comparison with steel, and some of the papers presented in this session give an indication of the problems which have arisen. The coolant gas in AGR is CO_2, and tests carried out in CO_2 at temperatures up to 750°C indicate that the corrosion resistance of beryllium is not entirely satisfactory. Both hot-pressed and warm-extruded material show protective oxidation in the early stages of testing, and subsequently undergo a rate transition giving more rapid but still protective rates of oxidation. In CO_2/H_2O gas mixtures, however, the initial protective period is followed by breakaway corrosion leading to accelerating oxidation rates. The addition of up to 2% of carbon monoxide to the gas is beneficial in that it delays the onset of breakaway.

Preoxidation of beryllium powder before consolidation is also reported to inhibit breakaway corrosion, presumably by producing a film of BeO around each particle. In the discussion on this topic it was reported that the addition of a small percentage of calcium to beryllium resulted in a material which was virtually unaffected by moisture in the CO_2 and was therefore very promising for AGR applications. The compatibility of beryllium with other reactor materials has also been examined at temperatures up to 600°C in vacuum and dry CO_2. All the conventional structural materials are incompatible with beryllium and only the more exotic metals such at tantalum, tungsten, niobium, molybdenum, etc., show little or no reaction.

The corrosion of beryllium in air at temperatures above 900°C and near-atmospheric pressures has been studied by American workers. They report an induction period of several minutes during which little corrosion takes place, followed by a transition to a rapid linear oxidation rate. The corrosion product formed in air, unlike that in pure oxygen or nitrogen, is not protective, but from the available results beryllium seems capable of withstanding any likely high temperature transient. For example, 2-3 hours in air at 900°C would give a weight gain of about 5 mg/cm².

The use of UO_2 as the fuel for AGR necessitates the use of small diameter cans ($\frac{1}{4}$-$\frac{1}{2}$ in) and has led to the multiple-rod-cluster type of fuel element. The fabrication problems which arise when considering the production of fuel elements, therefore, include extrusion of tube to within very close tolerances, production of rod for end caps, the development of welding procedures which will ensure integrity of containment, the manufacture of block from which end support plates can be machined, etc. (Fig. 4). Quality control is necessary at all stages.

In the various papers dealing with this subject details are given of the manufacturing techniques currently used for the fabrication of the various components. Two processes are available for the consolidation of powder, loose (pressureless) sintering and hot-pressing. A considerable amount of development work has been put into loose sintering in the U.K. but certain basic shortcomings remain and hot-pressing now seems to be the accepted method of consolidation in this country as well as in the U.S.A. Hot-pressed billets are fabricated to bar by hot extrusion at 1 000-1 100°C in steel cans to prevent oxidation.

For the production of tube from bar stock, warm extrusion in the range 500-900°C may be used with a lubricant such as silver. Alternatively, tube may be produced by hot extrusion of steel clad billets. With either method subsequent pickling is necessary to remove the lubricant or sheath. After fabrication beryllium tubing must be thoroughly inspected to ensure its integrity. In addition to the more conventional methods of non-destructive testing such as dye penetrants and radiography, eddy-current inspection techniques have been developed in this country and the U.S.A. and are making a real contribution to the maintenance of a consistently high quality product.

The effects of neutron irradiation on beryllium are probably more complicated than those in most other metals, since the transmutation of beryllium to helium by the (n, 2n) and n, α) reactions must be added to the normal irradiation effects. A number of workers in this country and abroad have examined the effects of neutron irradiations up to 6×10^{20} nvt at temperatures up to 700°C on the physical and mechanical properties of beryllium. Irradiation at 350°C produces hardening and loss of ductility in tests carried out at temperatures below the irradiation temperature, probably due to dislocation pinning by helium atoms. Some of this damage can be annealed out by heating above 500°C prior to testing.

Fig. 5.—Inter-granular surface of irradiated specimen after fracture at room temperature showing gas bubbles and discrete polyhedral voids.

Irradiation at 600°C apparently produces little change in yield strength or elongation, although some American in-pile stress rupture tests indicate that the stress-rupture properties at 600°C are reduced as a function of exposure, a flux of 3×10^{20} nvt producing a reduction of approximately 2 000 lb/in^2. Swelling due to helium formation is negligible at temperatures below 700°C although fractography of irradiated specimens has revealed the presence of fine gas bubbles within the grains and along grain boundaries (Fig. 5).

In beryllium irradiated under conditions that cause swelling, large bubbles appear in the grain boundaries. Restraint of the gas pressure in the bubbles depends on the strength of the beryllium matrix and reasonable agreement is shown between observed swelling and theoretical predictions. Under the likely operating conditions in the AGR it seems that beryllium may not be as seriously affected by neutron irradiation as might be expected at first sight.

Beryllium for Aircraft

Only four papers, all from the U.S.A., were submitted under this heading and dealt with the development of beryllium as a structural material for use in aircraft, missiles and spacecraft. The tendency is towards material of fairly high oxygen contents, up to 2 wt% BeO, with a minimum yield strength in excess of 30 000 lb/in^2. Ductility does not seem to be a major requirement, 1% being considered satisfactory. Considerable development work has been carried out on fabrication methods such as isostatic pressing and the machining of thin sections from large hot-pressed block, in order to obtain optimum mechanical properties. The high modulus of elasticity and low density of beryllium are also being used to advantage in precision gyro units for inertial guidance systems. The feasibility of using beryllium for structural components in missiles and spacecraft has been clearly established; its present high cost, however, makes it necessary for very careful consideration to be given to any specific application.

Metal Preparation and Fabrication

The desirability of studying very pure beryllium was expressed in the discussion on physical properties, and in the final session a number of papers were devoted to the means by which such a grade of beryllium could be prepared. Distillation is accepted as the most suitable method of purification although zone refining has also been examined. Impurities such as iron, nickel, manganese and chromium can be reduced to the 1-5 ppm range and Russian workers report that, excluding oxygen and carbon, total impurities as low as 30 ppm can be achieved.

The alloying of beryllium is a subject on which little information has been available, but a considerable amount of hitherto unpublished work was presented at the conference. One of the objectives has been to improve ductility, either by forming duplex alloys of the ductile matrix type, or by stabilizing the more ductile high temperature beta phase, but neither method has yielded very promising results as yet. The improvement of high temperature mechanical properties by ceramic or intermetallic dispersions has also been studied and in this field some success appears to have been achieved.

Factors influencing the sintering characteristics of powder have been examined; a high iron content is most beneficial, together with a low oxide value. Pressureless sintering has also been studied; it is attractive in the simplicity of the equipment required but difficulty is encountered in obtaining a product of consistently high density. As an alternative to the powder route for the production of ingots there has been developed the consumable-electrode vacuum-arc melting technique. This is essentially a more direct route than the conventional powder one. By eliminating the grinding operations it achieves a lower oxygen pick-up and, of course, casting is a much more rapid process than the consolidation of powder. No difficulties have been encountered in subsequent forging and rolling of this material and among the advantages claimed for it are superior ductility and machineability. Fabrication subsequent to the billet stage has been the subject of much development work and forging in particular was the topic of several papers. Forging is normally carried out on hot-pressed billets which may be clad or bare, but direct forging of encapsulated powder is also an established procedure. The forging of beryllium is attractive as a fabrication method since the amount of scrap metal produced on final machining of a component is reduced to a minimum.

To enable full benefit to be made of fabricated beryllium, various components must be successfully joined together, and for joining beryllium to itself or to other metals brazing with silver base or aluminium-silicon alloys has been used. For high temperature joints fusion welding is essential; this may be by inert-arc or electron-beam, the latter being preferred since it gives a finer grain structure and the weld is less prone to cracking.

Conclusions

In recent years our understanding of the physical metallurgy of beryllium has advanced considerably and it seems certain that before many more years have passed most of the outstanding questions will have been answered. In the production field, successful fabrication techniques have been evolved for the manufacture of virtually any component that may be required. As for the future prospects of beryllium, in the U.S.A. at least there is confidence that a steadily increasing demand will result in lower prices and thus make beryllium more competitive for applications other than aircraft and missiles. In the U.K. where the only major outlet appears to be as a canning material for nuclear reactors, the future is not so promising.

Extensions at Whessoe's Works

THE Whessoe Company has an impressive record of nuclear reactor pressure vessel construction. The company has built or has in hand some 14 reactor vessels. As times have changed Whessoe has expanded its interests to cater for the new demands—from railways to oil storage tanks just before the last war to reactor pressure vessels and liquefied gas storage in recent years.

On November 10, the Rt. Hon. Frederick Erroll, M.P., President of the Board of Trade, opened new extensions to Whessoe's welding shop at the Darlington works. Able to handle vessels of up to 125 tons, the shop has the most up-to-date equipment, including an X-ray building designed to take a 1 MeV source. The present source is a 400 KeV Pantak unit. The shop also has a stress-relieving furnace 85 ft long, 18 ft wide and 18 ft high with a working temperature of 400°C to 1 150°C. The new shop not only increases Whessoe's ability to make large pressure vessels but also frees space for the production of heat exchangers.

The new Whessoe welding shop has two 50-ton overhead cranes.

The latest version of the Mobot manipulator featured by Hughes Aircraft Company.

AtomFair '61

A special correspondent reports on the AIF/ANS jointly sponsored nuclear exhibition in Chicago

THE Atomic Industrial Forum and the American Nuclear Society jointly sponsored this year's AtomFair in Chicago, November 6-9, in conjunction with their annual conferences, continuing the arrangement resumed last December in San Francisco after a lapse of several years during which the AIF co-operated in an exhibit put on by the Nuclear Congress. The industry continues to be faced with the difficulties concomitant upon the existence of two national nuclear trade shows annually since the Engineers' Joint Council has announced its intention of holding another Nuclear Congress next June in New York City's Coliseum while the AIF and ANS have already begun signing up participants for AtomFair '62 to be held in Washington, D.C., next November.

The difficulty primarily is one of serving the interests of the various sponsors. The AIF directs its concurrent programme toward management personnel, the ANS presents a programme chiefly of technical and scientific interest, while the Engineers' Joint Council and its numerous participating societies are especially interested in a programme planned with the interests of the practical engineer in mind. Industry participants in the exhibition side of the meetings thus continue to be faced with the necessity of expensive participation in two shows in order to display their wares to everyone in the field. Behind-the-scenes negotiations have now been going on for five years or more in an attempt to resolve this difficulty with no definite solution yet in sight.

The Chicago AtomFair, nevertheless, was a notably successful one, partly at least because geographically the central location drew more participants than last year's show in San Francisco. Chicago, moreover, is becoming increasingly a centre for the nuclear industry, in the same way that Boston has developed a whole ring of nuclear companies. This development has probably been stimulated by the location nearby of the Argonne National Laboratory and by the successful operation by Commonwealth Edison Company's nuclear power plant at Dresden about 50 miles south of the city. It is odd, incidentally, that the man-in-the-street in Chicago is very little aware of the fact that he is a nuclear pioneer in the use of atomic-generated electricity and he is apt to greet this information with some surprise.

The timing of this year's exhibit had the advantage, too, over San Francisco so far as general attendance was concerned, November generally being a more convenient time than the busy weeks before Christmas. The number of participants in the AtomFair this year was 88, well up over last year's total though not as many as had been anticipated on the optimistic side. Attendance at each of the concurrent conferences, from which exhibit attendance is chiefly recruited, was extraordinarily good. Some 430 management personnel attended the AtomForum sponsored by the AIF, and the ANS had a record 1 200 participants at their conference. Press coverage of the various events, too, was unusually good, though somewhat disconcertingly the Press tended to ask more questions about fallout shelters and atmospheric contamination than about the prospects of economic nuclear power for peaceful purposes.

The nature of the exhibit this year continued to show a tendency which has become increasingly apparent over the years, away from the dramatic and toward the practical bread-and-butter aspects of the industry. **Westinghouse** and **General Electric,** who, as usual, dominated the show physically with their large and elaborate displays, continued to put their emphasis on reactors and their plans for large-scale economically competitive plants, but for the most part the remainder of the show directed its efforts toward supplier and other subsidiary aspects of the industry. The tendency is undoubtedly a healthy one, displaying as it does a grassroots interest—and profit—in the industry, as contrasted to earlier and rather visionary displays of just a few years ago. The AtomFair itself reflects very clearly the shakedown that has taken place in the industry since the halcyon days of 1956 and the withdrawal of a number of companies who discovered that their stake in the atom was marginal or perhaps premature.

Aside from a number of big companies who continue active in the reactor field—**American Machine and Foundry, Babcock and Wilcox, Allis-Chalmers, Combustion Engineering, General Dynamics, United Nuclear** (the new Olin Mathieson, Mallinckrodt, Nuclear Development Corporation of America, Sabre-Pinon combine), and the two giants of the industry, GE and Westinghouse—the emphasis of the current fair was heavily upon instrumentation.

Typical of the burgeoning interest and profit instrumentation was a newcomer to the fair, **Nuclear-Chicago Corporation,** which manufactures a variety of instrumentation for medical, biological, research and training purposes. **Nuclear Materials and Equipment Corporation** (NUMEC) displayed its Densitron, a device for measuring the density of mass-produced specimens that saves laborious hand calculation and a variety of other products, including the largest hafnium crystal bar ever grown. **Packard Instrument Company,** another company located in the

Operational check source, Model No. 5 by Anton Electronic Laboratories.

The Densitron unit by Nuclear Materials and Equipment Corporation will measure the density of mass produced components.

Chicago area, displayed its Tri-Carb scintillation spectrometer and auto-gamma spectrometer system.

Other local companies included the **Marvel-Schebler Products Division of Borg-Warner Corporation,** who design and manufacture control-rod drive mechanisms at their Decatur plant; **Instrument and Development Products Company,** manufacturers of shielding, detectors, low-noise amplifiers for solid-state detector and other products. **Radiation Counter Laboratories** manufactures transistor multi-channel analysers, laboratory instrumentation, a neutron activator and scalers and monitoring instruments. **Research Equipment,** which has its headquarters in nearby Wheaton, makes shielding windows, remote-positioning devices, periscopes and other devices; **Research Instrument Development Laboratory,** with a new line of small instruments.

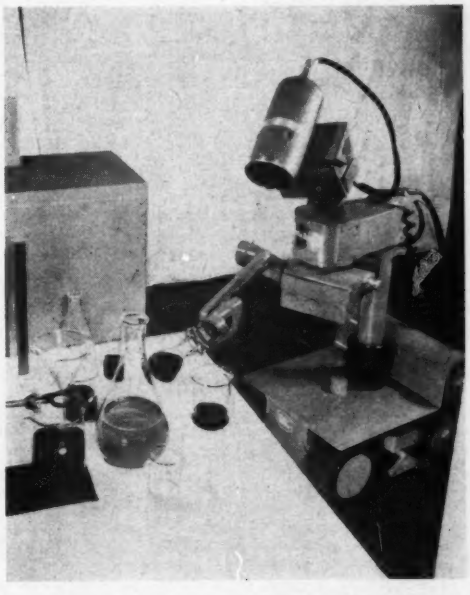
As usual the most conspicuous items on display at shows of this sort were the various master-slave manipulators. Star of this AtomFair was **Hughes Aircraft Company's** Mobot Mark III, a monster mobile manipulator with its science-fiction television eyes which made a great hit on local television and in the newspapers and caused some disappointment that the show, at least for its more spectacular elements, was not open to the general public. Only public participation, in point of fact, was a group of some 500-600 high school students and teachers who were shepherded in groups through the display as a part of the 1961 National Youth Conference on the Atom, sponsored by a number of electric utility firms and other organizations.

It is perhaps indicative of the general failure thus far to bring the state governments into the field of atomic energy control and participation that only two states—Florida, and, naturally enough under the circumstances, Illinois—took part in the AtomFair. Kentucky is the only state so far to move forward very aggressively toward taking over some regulatory responsibility from the AEC. The governor of Illinois, on the other hand, has only recently vetoed a bill which would authorize the state to take over some regulatory authority, on the fairly reasonable grounds that the state would be taking over a first-class administrative headache and getting nothing in return except a sense of responsibility ("World Digest," November, 1961).

Among other industrial participants in AtomFair '61 were:—**Aerojet-General Nucleonics** and its space power programme SPUR; **Baird-Atomic,** with a variety of its own products as well as those of firms which it represents, such as **Atomic Accessories, Sharp Laboratories, General Measurements** and **Controls for Radiation;** the **Brush Beryllium Company,** showing a variety of beryllium metal and oxide components; **Corning Glass Works,** shielding windows; **General Astrometals Corporation,** also beryllium products and graphite for nuclear and space applications, continuing the general emphasis in the show and in the conferences on the increasing similarity of interests between nuclear and space developments; **High Voltage Engineering** with its line of accelerators; **Kaman Nuclear,** neutron generators for activation analysis, and various study and experimental services; **Knapp Mills,** "Insmetals"; **Kollmorgan Corporation** and **Lerma Engineering Corporation,** periscopes; **Lionel Electronic Laboratories,** survey meters and monitors; **Metals and Controls,** fuel element work; **Sylcor,** fuel production; and **Technical Associates,** a line of health-physics monitoring instruments.

AtomFair '61 had the advantage of a show under the same roof as the concurrent conferences, in the basement exhibit area of the massive Conrad-Hilton Hotel. This advantage will obtain again next year when the exhibit will be held in the Shoreham Hotel in Washington at the same time as the Atomic Industrial Forum and American Nuclear Society conferences. A number of participants have already signed up for next year's conference. An especial attempt will be made at that time to encourage foreign participation. France's **Association Technique pour l'Energie Nucleaire** has already signed up for 3 000 square feet of space and it is hoped that a number of other governmental or industrial organizations abroad will also take part.

The word "realistic" has been a popular one in the nuclear industry for the last two or three years and the emphasis on this aspect has been probably what has been most marked at the current show. It is not, to be sure, as exciting a world now as it was a few years ago and few expect the miracles they once did but those who are left are committed and the space possibilities which have opened out keep the excitement alive, but for the most part everyone has learned to live with the difficulties and disappointments of a new field of endeavour. The group in Chicago, which is the convention city of the United States, discovered that they were sharing space and hotel accommodation with the National Real Estate Dealers Association (as well as the Methodists and the Girl Scouts). Without straining the nuclear exhibitors found that they could be as prosaically matter-of-fact about their respective businesses as the real estate men could—probably not the most inspiring realization in the world, but in many ways a reassuring one.



Another remotely controlled manipulator was the Little Ranger, shown by General Mills.

TRANSLATIONS

Orgel (508)

ORGEL est le premier projet d'EURATOM dans le domaine des réacteurs de puissance. Le réacteur projeté sera modéré à l'eau lourde et réfrigéré à l'aide d'un liquide organique, d'où son nom. Un programme de recherche étendu sera réalisé à l'aide des installations du centre d'Ispra et par l'intermédiaire de marchés passés avec l'industrie. Il permettra de déterminer les principales caratéristiques du réacteur de façon que la décision de construire puisse être prise au printemps prochain. Le programme envisage le développement de SAP, de combustibles à base de carbures, l'étude des problèmes de transfert de chaleur, du colmatage des canaux de refroidissement et les divers problèmes mécaniques et thermiques associés avec l'utilisation de tubes sous pression. Les caractéristiques physiques du système seront étudiées à l'aide d'un assemblage critique Eco, équipé d'un oscillateur à élément de chauffe. Cet assemblage devrait être en état de fonctionner en janvier 1963. L'avant-projet d'un réacteur expérimental appelé Essor sera mis au point pour juillet 1962. Essor permettra d'étudier de nombreuses questions et devrait être achevé en trois ans si la décision de construire est finalement prise.

Piqua (515)

Le réacteur expérimental de puissance de Piqua qui a été construit par Atomics International pour le commissariat Américain à l'énergie atomique sera mis en service au début de 1962. Rappelons que ce réacteur est modéré et réfrigéré à l'aide d'un liquide organique et qu'il aura une puissance électrique de 11,4 MW pour une puissance thermique de 45,5 MW. Cette installation sera la première qui permettra d'acquérir une expérience directe de l'opération des réacteurs de puissance organiques. Ce réacteur n'est pas accouplé à un turbo-alternateur; la vapeur produite est utilisée dans une centrale thermique voisine. Les caractéristiques principales du réacteur sont décrites par le présent article qui est illustré, entre autres, par une planche en couleur (No 35 de la série des réacteurs). Bien que les changements de conception aient été minimes depuis la parution de la première description du réacteur (voir page 68 de Nuclear Engineering de Février 1960), il n'a pas été possible de donner plus tôt tous les détails du système ainsi qu'une description complète des différentes parties du réacteur.

L'encrassage des réacteurs organiques (523)

La formation possible d'une pellicule de crasse à la surface d'un élément de combustible d'un réacteur organique peut conduire à une diminution des propriétés d'échange de chaleur du coeur. Des dépôts importants ne se produisent dans des systèmes non irradiés que lorsque la température est beaucoup plus élevée que celle qui est atteinte dans les parties du circuit extérieures au coeur des réacteurs organiques.

Mise au point de la fabrication d'éléments de combustible APM destinés au réacteurs á réfrigérant organique (525)

Leur résistance à haute température, leur haute conductivité thermique, leur faible absorption de neutrons et leur bonne résistance à la corrosion rendent les alliages APM particulièrement intélessants comme matériau de gaine et dans certains cas comme matériau de construction des éléments de combustible des réacteurs OMCR. Atomics International est en train de mettre au point un alliage APM M 257 destiné au gainage des combustibles réfractaires (tels que UO_2 ou UC) qui offrent la possibilité de taux de combustion élevés et d'un cycle de combustible bon marché.

Orgel (508)

Der erste bedeutende Vorstoss der Euratom in das Gebiet der Leistungsreaktoren ist das "Orgel"-Projekt. Dieses Reaktorsystem leitet seine Kurzbezeichnung von "Organique Eau Lourde" her, ist also schwerwassermoderiert und-gekühlt. Ein umfrangreiches, teils im neuen Forschungszentrum Ispra anlaufendes und teils in Form von Industrieaufträgen vergebens Arbeitsprogramm verfolgt als erstes Ziel die Erarbeitung der wesentlichen Konstruktionselemente dieses Reaktorsystems, was eine Entscheidung über die Konstruktion im Frühling nächsten Jahres ermöglichen soll. Das Programm umfasst die Entwicklung von gesintertem Aluminiumpulver und Karbid-brennstoffen sowie die Untersuchung der bei Brennstoffelementen auftretenden wärmeübertragungsverhindernden Schichten und der verschiedenen mechanischen und thermischen Probleme von Druckröhren. Die physikalische Seite des Systems soll in der mit einem geheizten Pendelement versehenen kritischen Anlage ECO untersucht werden, deren Inbetriebnahme für Januar 1963 vorgesehen ist. Vorläufige Pläne für einen Mehrzweck-Versuchsreaktor Essor sollen im Juli 1962 fertiggegestellt sein; vorbehaltlich der Genehmigung dieses Projektes dürfte der Bau in etwa drei Jahren erfolgen.

Piqua (515)

Der von der Atomics International für die U.S. AEC gebaute organisch moderierte und gekühlte Leistungs-Versuchsreaktor in Piqua soll planmässig Anfang 1962 in Betrieb genommen werden. Mit einer elektrischen Ausgangsleistung von 11,4 MW bei einer Wärmeleistung von 45,5 MW des Reaktors ist dies die erste Anlage, die unmittelbare Betriebserfahrungen mit organischen Leistungsreaktoren ermöglichen wird. Die wesentlichsten Merkmale dieser Anlage, die übrigens selbst keinen Strom erzeugt—der Dampf wird einem benachbarten konventionellen Kraftwerk zugeleitet—werden in dem mit einer Schnitzeichnung illustrierten Artikel (World's Reactors No. 35) beschrieben. Obgleich die seit der ersten Beschreibung der Anlage in "Nuclear Engineering" (Februar 1960, Seite 68) vorgenommenen Konstruktionsänderungen unbedeutend waren, ist es erst jetzt möglich, das System und die Einzelteile des Reaktores in aller Ausführlichkeit und Endgültigkeit zu schildern.

Die Bildung von Isolierschichten in organischen Reaktoren (523)

Mit der Bildung von dünnen isolierenden Schichten auf der Oberfläche der Brennstoffelemente in einem organisch gekühlten Reaktor ist die Möglichkeit einer Verschlechterung der Wärmeübertragungseigenschaften des Kerns gegeben. In unbestrahlten Systemen treten merkliche Ablagerungen nur bei Temperaturen auf, die weit über den für ausserhalb des Kerns verwendeten Bauteilen in Frage kommenden liegen.

Entwicklungen in der Herstellung von APM-Brennstoffelementen (525)

Hohe Warmfestigkeit, grosses Wärmeleitvermögen, niedrige Neutronenabsorption und gute Korrosionsfestigkeit machen APM (Aluminium Powder Metallurgy)*-Legierungen ganz besonders zur Ummantelung und in manchen Fällen zum konstruktiven Aufbau von Brennstoffelementen für organisch moderierte und gekühlte Reaktoren geeignet. Atomics International entwickeln gegenwärtig eine APM-Legierung M 257 zur Ummantelung von keramischen Brennstoffen (wie UO_2 und UC), die die Möglichkeit grossen Abbrandes und niedriger Kosten für den Brennstoffzyklus bieten.*

Orgel (508)

El primer paso dado por Euratom en el campo del perfeccionamiento del reactor para energia, como proponente principal lo ha constituido el proyecto Orgel, derivándose esta palabra de "Organique Eau Lourd," es decir un sistema de reactor con moderación por agua pesada y enfriamiento orgánico. Teniendo como base el nuevo centro de estudios de Ispra y contratos industriales, se ha organizado un amplio programa de investigaciones científicas, en primer lugar, para avaluar las características esenciales de concepción de este sistema de reactor con vistas a tomar una decisión sobre su construcción en la primavera del año próximo. El programa comprende el perfeccionamiento de SAP, combustibles de carburo, estudios sobre ensuciamiento de transferencia de calor y los diversos problemas relacionados con los tubos a presión, de índole mecánica y térmica. La física del sistema se estudiará en un Eco de conjunto crítico, dotado de un elemento oscilador calentado, y se proyecta que empiece a funcionar en enero de 1963. Para julio de 1962 se espera estén listos planos para un Reactor Essor experimental adaptable que, siempre que se obtenga el permiso para proceder, debiera construirse en tres años.

Piqua (515)

El reactor de demostración para energía de Piqua, con moderación y enfriamiento orgánicos, que ha sido construido por la Atomics International para la U.S.AEC tiene su inauguración prevista para principios de 1962. Con un rendimiento eléctrico de 11,4 MW obtenidos de un reactor térmico de 45,5 MW, esta instalación constituirá la primera facilidad de la que pueda obtenerse una experiencia de explotación directa sobre reactores de potencia orgánicos. Las características sobresalientes de esta instalación, que debe recordarse no comprende equipo generador ya que el vapor pasa por tuberías directamente a una central eléctrica convencional cercana, se describen en el artículo al que acompaña una vista recortada de la instalación (World's Reactors No. 35 (Reactores del Mundo No. 35)). Aun cuando los cambios de concepción desde que se describió esta instalación por primera vez en "Nuclear Engineering," Febrero de 1960, página 68, han sido de menor importancia hasta ahora no ha sido posible dar detalles completos del sistema y descripciones definitivas de los elementos del reactor.

Ensuciamiento en Reactores con moderador orgánico. (523)

La posibilidad de acumulación de película aislante "ensuciadora" sobre la superficie de un elemento combustible en un reactor con enfriamiento orgánico pudiera conducir a la reducción de la capacidad de transferencia de calor del núcleo. Depósitos importantes en sistemas no irradiados ocurren solamente a temperaturas muy superiores a las calculadas para aplicación en elementos externos al núcleo de reactores orgánicos.

Perfeccionamiento en la fabricación de elementos APM para combustible (525)

Resistencia a altas temperaturas, alta conductividad térmica, baja absorción de neutrones y buena resistencia a la corrosión son caraterísticas que hacen que las aleaciones APM resulten especialmente adecuadas para revestimiento y, en algunos casos, como material estructural para elementos combustibles OMCR. La Atomics International está perfeccionando una aleación APM, la M 257, como revestimiento de combustible para combustibles en cerámica (tales como UO_2 ó UC) que ofrecen la posibilidad de una alta combustión y bajos costos de circlo.

Personal

Appointments—U.K.

Sir Leonard Owen, due to retire from full-time membership of the AEA on June 31, 1962, as part-time member for 1962-64. He will continue to act as chairman of the boards of management of the production and engineering groups.

Lord Citrine, re-appointed part-time member of the AEA, from January 1-December 31, 1962.

Dr. J. V. Dunworth, deputy director of the AEE, Winfrith, as deputy director of the National Physical Laboratory.

Mr. B. D. Baines, formerly technical sales manager of the Hawker Siddeley Nuclear Power Company and sales manager of Nuclear Engineering, the betatron manufacturers, as technical sales manager of the Nuclear Chemical Plant, and **Mr. T. V. Molesworth,** formerly with the AEA at Windscale, as senior chemical engineer.

Mr. E. B. Bell, chief engineer of Saunders-Roe and Nuclear Enterprises, Hayes, Middlesex, as general manager.

Sgr. M. Macioti, of Euratom, as scientific secretary to the European Coal and Steel Community delegation in London. His responsibilities will cover not only coal and steel affairs but also nuclear subjects.

Mr. G. Nelson, managing director of English Electric, as chairman of their subsidiary, D. Napier and Son; **Mr. G. A. Riddell,** becomes a director and deputy chairman, and **Mr. P. J. Daglish,** managing director. **Mr. H. E. C. de Chassiron** has resigned as managing director but retains his seat on the board.

Mr. T. D. W. Angwin, chief resident engineer at Hunterston nuclear power station, as assistant general manager of GEC's Erith Works, which is now under the control of the new company, GEC (Engineering), and **Mr. J. C. Morris,** previously commercial manager of the United Power Company, as commercial manager (export projects) of the new company.

Mr. Raymond E. Purves, chairman and managing director of the Clyde Industries Group, Australia, and a governor of the Australian Nuclear Research Foundation, as a director of The Fairey Company.

Mr. E. E. Webster, management executive of The Plessey Company, as general manager.

Dr. Baqir Husain Hasani

Dr. I. H. Usmani

Professor Lajos Janossy

Dr. A. V. Crewe

Mr. R. N. Millar, managing director of GEC's engineering group, as chairman and managing director of the new company, GEC (Engineering) (see "Industrial Notes"). Other members of the board are **Dr. K. J. Wootton,** who remains general manager of the Erith works; **Mr. T. H. Kelsey,** general manager of the Witton works; **Mr. C. J. O. Garrard,** commercial manager; **Mr. E. Nicholson,** financial director; **Dr. H. K. Cameron,** development director; **Mr. G. M. F. Donnelly,** production director; **Mr. W. D. Morton,** personnel director and assistant works manager of the Witton works; and **Mr. J. E. Thomas,** secretary.

Mr. R. Chaffey, export manager of Marconi Instruments, as deputy commercial manager.

Mr. J. E. Swainson and **Mr. A. S. Moseley,** as directors of Permali, Gloucester.

Overseas

Dr. Baqir Husain Hasani, of Iraq, as chairman of the IAEA board of governors, in succession to **Mr. Allen D. McKnight,** of Australia. A graduate of Columbia University, New York, and the Law College, Baghdad, Dr. Hasani has held various important administrative posts in his country including the director generalship of taxation and chairmanship of the Tobacco Monopoly Administration, and has been Iraqi delegate to several U.N. and other meetings and conferences.

Professor Lajos Janossy, vice chairman of the Hungarian National Atomic Energy Commission and professor of atomic physics at Budapest University, and **Dr. I. H. Usmani** chairman of the Pakistan Atomic Energy Commission, as vice chairmen of the IAEA board of governors.

Dr. A. V. Crewe, director of the particle accelerator division of Argonne, as director of the laboratory, in succession to **Dr. Norman Hilberry,** who is retiring. Dr. Crewe, who was born in Bradford, England, in 1927, is a graduate of Liverpool University and took an active part in the construction of Britain's first diffusion cloud chamber and of equipment for Liverpool's synchrocyclotron. In 1952 he joined Chicago University's research staff and acted as consultant on accelerator projects in Sweden and Argentina. While at Argonne he has directed much of the design and construction of the Zero Gradient Synchrotron (ZGS).

Mr. C. R. Braun, manager of the Allis-Chalmers nuclear power department at Greendale, Wisconsin, to the new position of manager of marketing for the company's atomic energy division. His place at Greendale, where most of the R and D on the Pathfinder project has been carried out, is taken by **Mr. C. B. Graham,** chief engineer of the atomic energy department there since 1956.

Dr. Ralph D. Bennett, director of research of the Martin Company, as a vice president and head of the company's nuclear division.

Awards

Dr. Robert Hofstadter, professor of physics at Stanford University, and **Dr. Rudolf Mössbauer,** of the Technische Hochschule, Munich, have been jointly awarded the Nobel Prize for Physics; Dr. Hofstadter for his investigations into the structure of atomic nuclei and Dr. Mössbauer, who is only 32 years old and is working at the California Institute for Technology on a Bundes Ministry of Atomic Energy scholarship, for his research into gamma radiation and the discovery of the "Mössbauer effect."

Mr. Robin Guard, chief engineer of the nuclear energy division of Kennedy and Donkin, the consulting engineers, has been awarded the Gold Medal of the Junior Institution of Engineers for a paper on nuclear fuels.

Obituary

Nuclear Engineering regrets to announce the deaths of:—

Dr. B. L. Goodlet, managing director of the Brush Electrical Engineering Company and from 1950-56 head of the reactor engineering research and development division at Harwell. While at AERE he was in charge of the design study which led to the gas-cooled reactors installed in Calder Hall. He was 58 when he died.

Mr. N. W. Shaw, deputy chief engineer of the nuclear energy department of W. S. Atkins and Partners, while on business in Cairo. He was 53.

M. Jean Dyfrenne, the French permanent delegate to the IAEA Vienna.

Dr. J. V. Dunworth

Mr. B. D. Baines

Mr. T. V. Molesworth

Sgr. M. Macioti

Industrial Notes

A new company, **GEC (Engineering),** has been formed to take over and develop the engineering activities of the GEC. The electrical engineering works at Witton, Birmingham, and the mechanical engineering works at Erith, Kent, will come under its control. Headquarters will be situated in London in premises yet to be acquired. Work carried out at Erith by the former GEC atomic energy division is now undertaken by the United Power Company, except for the manufacture and sale of power manipulators. These will be the responsibility of the new company.

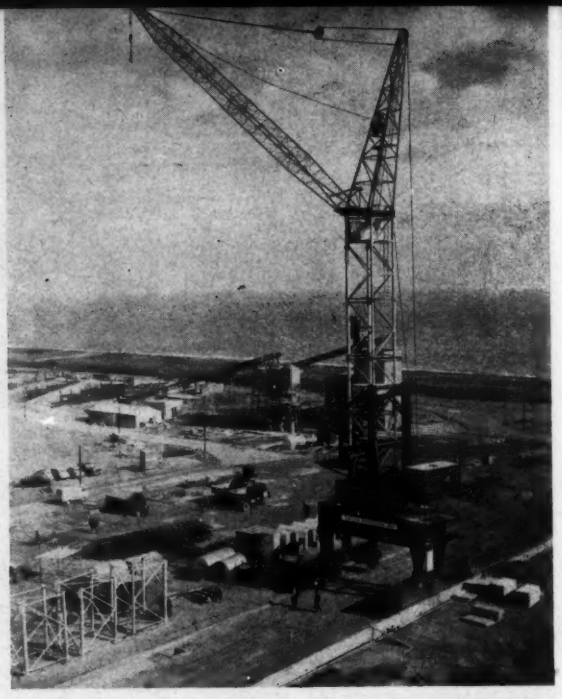
Plans for the expansion of **Tube Investments'** research and development organization include the setting up of a new iron and steel research department at Rotherham and an engineering development design office for advancing the specialized engineering of process plant. In addition, a new organization for the steel tube division is to be evolved from the TI Technological Centre at Walsall. The British Aluminium Laboratory at Gerrards Cross will continue to follow research and development on the manufacture and uses of aluminium and its alloys. Development work in the engineering, electrical and cycle divisions will be carried out mainly by the companies concerned, with the co-operation where needed of the metallurgical laboratory at Hinxton Hall, Cambridge, which is concerned with physical metallurgy and metal physics, and the new design office. An additional section of the central TI organization is the department of technical information at Birmingham. Expenditure on research and development during the next two years is expected to be considerably greater than in previous years.

Cathodic protection of the c.w. system at Dungeness is to be supplied by **Metal and Pipeline Endurance.** The protection will cover pumps, pipelines, water boxes, intake and outfall structures.

The Heavy Plant Division of **AEI** is manufacturing the eight gas blowers to be installed in the Dungeness nuclear power station. Each blower, of the single-stage overhung-axial type, will be capable of dealing with 1·25 ton/s of CO_2. The blower casings will be spherical with a diameter of approximately 15 ft and will have four flanged 6·5-ft-dia. branch openings.

Euratom have ordered from **Nuclear Equipment** of Watford, Herts, a GM 300 general purpose 750 lb capacity manipulator for installation at the Ispra research laboratories. Since it was formed three years ago by Savage and Parsons and General Mills, Nuclear Equipment has built up a flourishing export business and during the past nine months orders totalling £100 000 have been obtained from atomic energy authorities in Belgium, Denmark, Norway, France, Germany and Italy. During the same period 29 slave manipulators were also ordered by the U.K.AEA and four for use at Bradwell.

Hayward Tyler and Company recently supplied four large heavy water pumps to **De Laval Ljungstrom Pumps AB,** for installation in the Agesta nuclear power plant near Stockholm.



The 10-ton-capacity tower crane specially built for use on the Sizewell nuclear power station site by Norddeutsche Maschinen-und Schraubenwerke, Peine, Hanover. When extended to its full height the tower is 220 ft and the lifting boom is capable of being raised to 320 ft. As reported in "World Digest," progress on the site is ahead of schedule. The station is being built for the CEGB by the English Electric Babcock and Wilcox Taylor Woodrow Atomic Power Construction Company.

Both Olympia and Earls Court are to be used for housing the first **London International Engineering Exhibition,** April 23-May 3, 1963. To be organized by **F. W. Bridges and Sons,** and **Industrial and Trade Fairs,** it will replace the Engineering, Marine, Welding (and Nuclear Energy) Exhibition, the first of which was held in 1906. Some 1 200 exhibitors are expected to take space and as the exhibition is timed to coincide with the Hanover Fair, Germany, it is expected to attract a record number of overseas visitors.

A new instrument assembly wing to the **Cambridge Instruments Company's** works at Cambridge, was opened by the Minister of State at the Board of Trade, Sir Keith Joseph, on October 23. A two-storey building, the new wing provides an additional 15 000 ft² of work area, part of which is already in use for production of the Microscan X-ray analyser.

Some 100 companies and organizations were represented at the **Engineering, Materials and Design Exhibition,** Earls Court, London, November 13-18. It was organized by **Industrial and Trade Fairs,** and opened by Sir William Penney, deputy chairman of the U.K.AEA.

Cambridge Instrument Company are to establish with **Istrumenti di Misura,** of Milan, a jointly owned company for the manufacture and sale in Italy of Cambridge designed equipment.

English Electric and **Les Exploitations Electriques et Industrielles,** Paris, have set up a company, **La Compagnie Continentale d'Equipments Electriques (CEE)** to carry out the manufacture and sale of all types of electric and electronic control equipment in France and the Common Market countries.

Johnson, Matthey and Company have acquired a majority shareholding in the Belgian precious metal company, **Pauwels Freres,** of Brussels, now known as Johnson, Matthey and Pauwels. Johnson, Matthey also have trading and manufacturing interests in France, Holland, Italy and Switzerland.

Brevatome, Paris, have granted **Metallurgie et Mecanique Nucléaires,** Mol, Belgium, a licence to use processes and equipment as developed by the **Commissariat a l'Energie Atomique** and **Nobel-Bozel** for the nickel plating of uranium.

The U.S.AEC have extended for five years their contract with the **Phillips Petroleum Company** for the operation of the MTR, ETR, SPERT, chemical processing plant and central plant facilities at Idaho Falls. The contract also covers research and development work.

Radiation monitoring equipment, radioactive material handling and storage apparatus, and medical diagnostic scanners worth $80 000 have been supplied to the Korean Government by **Tracerlab.** Funds were made available through a $117 000 grant from the U.S.AEC.

Hagan Controls, a member of the Plessey Group, have moved to Weedon Road, Northampton. Phone. Northampton 260.

Strachan and Henshaw have moved their office headquarters to the company's new works in Ashton Vale Road, Bristol, 3.

MEETINGS

December 7-8.—The Institute of Metals, at Church House, London, S.W.1. **Sintered High-Temperature Oxidation-Resistant Materials,** a symposium.

December 12.—The Institute of Metals, South Wales Section, in the Metallurgy Department, University College, Swansea, at 7 p.m. **Some Theoretical Aspects of the Sintering of Metal Powders,** G. A. Geach.

December 14.—Institution of Mechanical Engineers, Nuclear Energy Group, Western Area Branch, at the University Engineering Laboratory, Bristol, at 6 p.m. **Maintenance Experience of the Calder Reactor,** J. R. Treherne.

December 14.—Institute of Marine Engineers, at the Royal Station Hotel, Kingston-upon-Hull, at 7.30 p.m. **Looking Back on Nuclear Propulsion,** R. P. Williams.

December 14.—Southampton Metallurgical Society at Southampton University, at 7.15 p.m. **Fatigue,** T. R. G. Williams.

December 14.—The Society of Instrument Technology, Bristol Section, in the Department of Physics, Bristol University, at 7.30 p.m. **The Atomic Clock,** L. Essen.

Processes and Equipment

For further information on any item please enter the relevant number on one of the Reader Service Cards enclosed with this issue.

A portion of the furnace being used for stress-relieving a large fabricated unit.

Large Stress-relieving Furnace

What is believed to be the world's largest stress-relieving furnace is being installed at the Thornaby-on-Tees works of Head Wrightson Teesdale Ltd. Measuring 27 ft × 27 ft × 80 ft long, the furnace will have a capacity of, for example, three 26-ft spheres, and is capable of stress-relieving such large items as oxygen steel converters. It will be used in the construction of the heat exchangers for Dungeness.

Designed by Cooper Electroheat Ltd., the furnace incorporates many departures from previous practice. No firebrick is used in its construction, which is principally of 8 ft × 8 ft mild steel panels filled with compressed mineral wool slabs and secured by flexible mild steel sheeting. Roof panels are secured to longitudinal steel joists at building roof truss height, while the side walls are supported by A-frames on transverse bogies. The end walls are lifted in two sections by a mobile crane, while the floor, also in panel form, is carried by bogies which also carry the cradles supporting the load. In addition to low capital cost and ease and speed of erection, this construction enables the furnace to be extended or to be dismantled and re-erected at another works, if required.

Further advantages of this type of construction are the low thermal capacity of the mineral insulation and, due to the absence of flue made possible by electrical heating, the negligible oxidation and scaling obtained. The heating elements are installed in stainless steel channels, resting on steel frameworks on the furnace floor. Elements are grouped in units of 40 kW, each comprising 12 coiled elements in sintered alumina sleeves; the total capacity is about 1·5 MW. Using the furnace during off-peak hours, stress-relieving can, it is stated, be carried out for about £1 per ton.

About half the length of the furnace (40 ft), when completed, was used to stress-relieve a heavy fabrication; temperature limits of 610°C-630°C were achieved.

(**Cooper Electroheat Ltd.**, 164 Lord Street, Southport, Lancs.)

1168

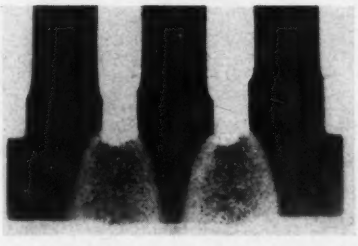
Electron-beam Machining

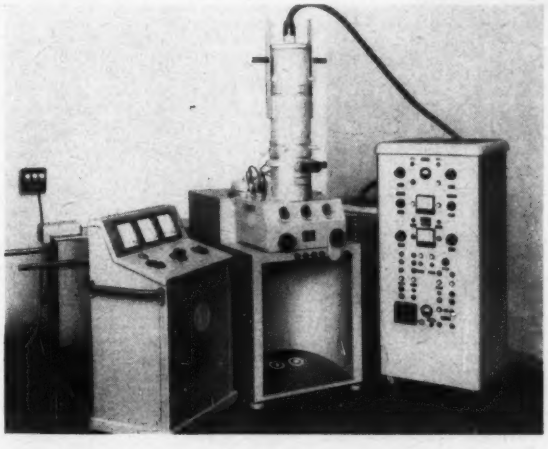
The use of electron-beam techniques for welding is well known, and has been previously described (*Nuclear Engineering*, January, 1960, p. 19). Developments announced by the Carl Zeiss Foundation of Oberkochen, W. Germany, extend the use of focused electron beams to drilling and cutting, as well as welding. Energy densities in the beam are said to be as high as 500 MW/cm² and beam focus is said to be sharp enough to enable a sharply defined spot only 0·003 mm diameter to be melted. In the fields of milling and drilling it is possible to cut virtually any profile required.

On account of the extremely fine focus, welding can be so controlled that surrounding material is virtually unaffected so that distortion is reduced to the minimum. Machines are available with vacuum chambers long enough to accept work pieces up to 8 m (26 ft 3 in) in length.

(**Degenhardt and Co., Ltd.**, 6 Cavendish Square, London, W.1.)

1169





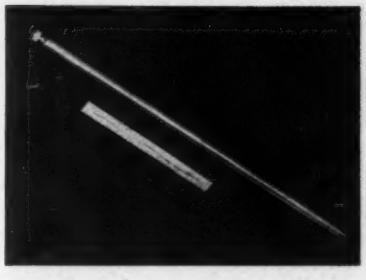
Above:—X-ray of Zircaloy welding on a fuel element: approximate magnification 7×.

Left:—Zeiss electron-beam plant.

Proportional Counters

New Plessey proportional counters have been developed which, suitable for low-power flux measurement in reactor work, can be used almost immediately after long periods of exposure to high values of neutron flux. The counter can be used, therefore, for low-level counting work without the necessity of mechanical withdrawal at power levels.

Constructed of high-purity aluminium, the counters have an enriched boron lining and



Right:—Two of the new Plessey proportional counters.

inert gas filling, with ceramic insulators and ceramic-to-metal seals. Three types are available, all 1 in diameter, with sensitive volume lengths of 8, 16 and 24 in (overall lengths 14½, 22½ and 30½ in, respectively). Operating sensitivity varies from 9 c/nvt to 3 c/nvt, with an EHT supply of 750 V. Limitations of operation are given as 1 200 V; 70°C and a neutron flux of 10^{10} nv; the limiting total doses are quoted as 5×10^{9} rad for gamma and more than 10^{14} nvt for neutrons.

(**Plessey Nucleonics Ltd.**, Weedon Road, Northampton.)

1170

Vacuum Permeability Test Rig

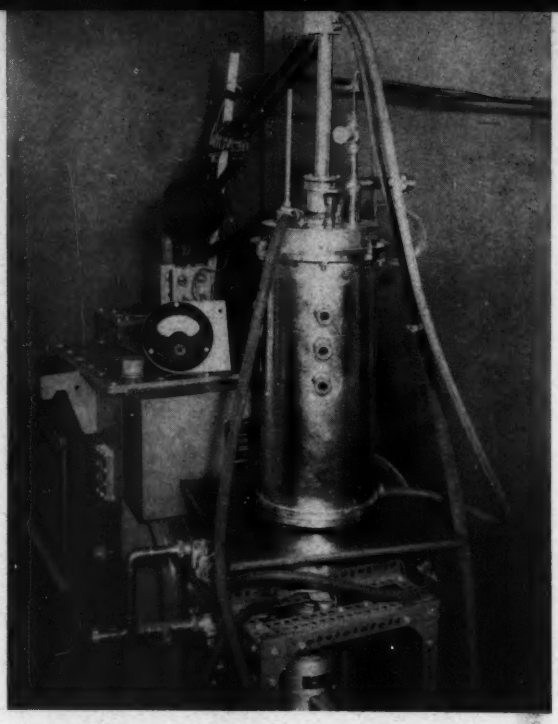
Destined for the Dragon project, a test rig has been designed for determining the permeability of graphite cladding under a range of temperatures and tensile stresses.

The body of the unit is a cylindrical water-jacketed shell of stainless steel provided with sight windows that can be covered with internal shielding discs to prevent vacuum deposits on the fused quartz windows. This main shell is mounted directly over an oil-diffusion vacuum pump, backed by a rotary pump.

Inside the shell are three concentric radiation shields, of copper, molybdenum and tantalum, respectively, which encircle the specimen and its holder. These are attached to a system of water-cooled concentric tubes with O-ring seals, which enable current from a single-phase transformer to be passed through the specimen for heating purposes whilst, at the same time, permitting tensile loading of the specimen. Argon is admitted to the inside of the specimen and the diffusion through the graphite evaluated by mass spectrometer techniques at various tensile loadings and temperatures up to 2 300°C.

(Spembly Ltd., New Road Avenue, Chatham, Kent.)

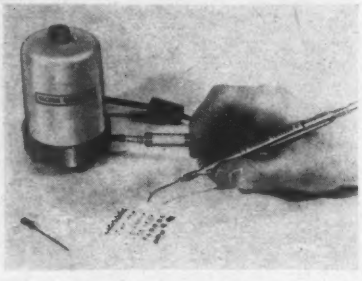
1171



The Spembly vacuum permeability rig on test.

Vacuum Tweezers

Delicate work with very small components is facilitated by a vacuum pick-up device developed by the Vacuum Tweezer Co. of New Jersey, and now being marketed in Britain. An electromagnetic vacuum generator of small size, directly operated from lighting mains, is coupled through a filter by flexible tubing to a pencil tip of about the same size as an artist's air-brush, furnished with a pick-up tip which becomes operative when a hole in the body of the unit is covered with the finger; uncovering the hole again will release the component picked up.



Vacuum tweezer unit in use.

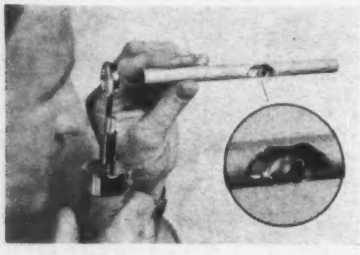
(L. E. Simmonds Ltd., 5 Byron Road, Harrow, Middlesex.)

1172

Bore Inspection

Inspection of the inner surfaces of holes as small as $\frac{1}{16}$ in (4·8 mm) is possible by the use of a new range of bore viewers, consisting of a probe with a miniature lamp for illuminating the walls of the hole and an elliptical mirror unit which is observed from outside the hole through a lens carried by the handle containing the battery. The unit is simple and robust, suitable for workshop use. Two sizes are available; for holes from $\frac{3}{16}$ in to $\frac{9}{16}$ in (4·8-14·3 mm) and for $\frac{7}{16}$ in to $1\frac{1}{4}$ in (11·1-31·8 mm) diameter. Lengths available are 2 in, 6 in and 8 in; magnification with the shorter unit is 4 X and, for the other two units, 2 X. Introscopes of lengths up to 30 ft, in many different diameters and with heads for all angles of view, are made by the same company.

The Allen bore inspector.



(P. W. Allen and Co., 253 Liverpool Road, London, N.1.)

1173

BRIEFLY . . .

A new range of rotary seals has been developed by **Crane Packing Ltd.**, of Slough, Bucks. Known as the types 51B and 52B they have a nominal design pressure of 1 500 psi. Important features are pressure-compensated carbon seal faces for sizes above 30 mm shaft diameter; extended surface seats for good heat dissipation; positive drive by keys and keyways. Sizes at present covered by the range are 15 mm-100 mm in 5 mm steps; larger sizes can be supplied but are not yet standard. The 52B type has no rubber O-rings and is intended for highly corrosive services. **B314**

New Du Pont resistor compositions for dipping, brushing or screen printing are being marketed by **Brown and Forth Ltd.**, Clifton House, 83-117 Euston Road, London, N.W.1. Three compositions are available, the approximate ohmic values being 500, 3 500 and 10 000 ohms/in² for films 0·001 in thick. After firing, the film is relatively insensitive to moisture, abrasion and ambient temperatures up to 125°C, the effect of dip soldering for printed circuit work being negligible. The temperature coefficient is approximately 350 ppm/°C. **B315**

Claude Lyons Ltd., Valley Works, Hoddesdon, Herts, have announced that in future they will handle all British and Commonwealth sales of Variac variable transformers, which have hitherto been available either from themselves or from the Zenith Electric Co., Ltd. In all other respects, the business of the two companies will be carried on independently as before. **B316**

A stick-on label with a difference is to be found in the Magnoplate, produced by **Millett Levens Ltd.**, Stirling Corner, Borehamwood, Herts. Rigid or flexible, the nameplate contains a magnetic powder dispersed in a plastics base and can readily be attached, either permanently or temporarily, to a ferrous metal object. **B317**

"Pallseal," a compound V-ring sealing unit, is announced by the **Pall Corporation**, 30 Sea Cliff Avenue, Glen Cove, New York. Constructed of Du Pont "Viton" moulded into a ring of Armco 17-4PH stainless steel, it is re-usable and corrosion-resistant. Temperature limits are said to be −65°F to 500°F, and working pressures up to 10 000 psi. **B318**

The **Wayne Kerr Laboratories Ltd.**, 44 Coombe Road, New Malden, Surrey, have developed a new precision electrometer of extremely high sensitivity, drawing virtually zero energy from the measurement source. Full-scale deflection can be obtained with 1 mv or 10^{-15} A. **B319**

Thos. Firth and John Brown Ltd., Atlas Works, Sheffield 4, announce a new high-speed steel known as "Speedicut Vanleda" containing 5% vanadium and cobalt, with a high percentage of the vanadium present in the form of carbide. This material is said to be extremely useful where conditions such as lack of rigidity militate against the use of sintered carbide tips. **B320**

Under their collaboration agreement with the U.K.A.E.A., **W. J. Fraser and Company Ltd.**, Harold Hill, Essex, are manufacturing plants for HF recovery from aqueous solutions, a process which attracted considerable attention at the recent Achema exhibition. **B321**

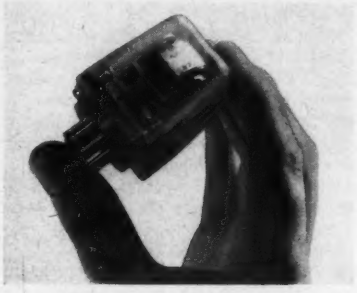
Electronics and Automation (London) Ltd., Maxwell House, Arundel Street, London, W.C.2, have commenced marketing the "Etromat" rechargeable torch battery, after three years' testing in service. The device, which is the size of two U-2 cells, for all voltages from 2·5 to 6 V, is recharged from 110-250 V mains by means of a built-in rectifier; removal of a cap switches in the rectifier and exposes a 2-pin plug. Both light-duty and heavy-duty types are available. **B322**

The Pyrene Co., Ltd. (Metal Finishing Division), Great West Road, Brentford, Middlesex, have introduced the Bonderit "250" series of processes to deposit chromate coatings, having improved corrosion-resisting properties, on galvanized steel (hot dip or electro-zinc) or zinc-based alloys. The "250" processes operate at room temperature. **B323**

Reduction in prices of Araldite epoxy resins are announced by **CIBA (A.R.L.) Ltd.**, Duxford, Cambridge. **B324**

Small Plug-in Relay

Weighing less than 3¼ oz (approx. 92 g) and having dimensions of 2¾ in × 1⅝ in × 1⅞ in (70 × 48 × 35 mm) the new Dewhurst type EB relay is a double-pole change-over unit which is capable of heavy duty (up to 3 600 operations/h), the contacts having



(Left) The new Dewhurst plug-in relay, showing the compact design.

a switching capacity of 6 A at 250 V, or 2 A at 400 V a.c.

Standard operating coils are wound for either 24 or 220 V a.c., but coils can be supplied for a.c./d.c. operation in the range 6-110 V, or, with series resistor, for 220 V d.c. or 400 V a.c. Operating times on a.c. are approximately 10 msec for closing and 8 msec for release; on d.c., both close and release times are 8 msec.

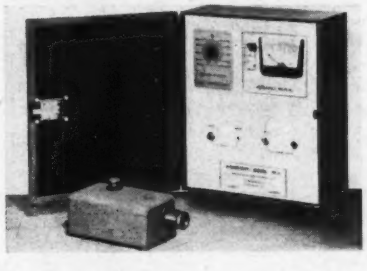
Enclosed in dustproof plastics case, the relay is usually supplied with an international octal base, but plug-in baseplates for solderless wiring are available.

(Dewhurst and Partner Ltd., Inverness Works, Hounslow, Middlesex.)

1174

Radiation Thermometers

Through arrangements made with the Radiation Electronics Corporation (a division of the Comptometer Corporation) of U.S.A., new temperature measurement instruments are now being marketed in Britain. "Thermodot" radiation thermometers are available in a range of precision units for research work and more rugged



The industrial model "Thermodot" radiation thermometer.

types for industrial use. The research unit, provided with an optical chopper, is capable of recording transient phenomena as brief as 10 μs, and of responding to radiation temperatures as low as 100°F (38°C); the industrial unit will measure temperatures down to 180°F (82°C) and can be used with an indicating controller.

In addition, a range of infra-red scanning equipment is available, for remote scanning of a temperature pattern, either line-scanning, producing a temperature profile over a narrow strip, or area scanning. Operating temperatures range from room temperature upwards.

(West Instrument Ltd., 52 Regent Street, Brighton, Sussex.)

1175

Shielding Windows

The use of multiple slabs of high-density glass for hot-cell windows has previously been referred to in these pages (*Nuclear Engineering*, August, 1957, p. 315), and the manufacture of high-lead glass by the batch process in August, 1957, p. 333, and by the continuous process in December, 1957, p. 526.

(Right) One of the 7-ton shielding windows supplied to Windscale.

Illustrated is one of four windows supplied to the U.K.AEA for the Windscale caves. Each window, which is 36 in × 48 in on the hot side, and 26 in × 38 in on the outer side, is made up of five blocks each 10¼ in thick and one block 9¼ in thick, the glass having a density of 2·67 g/cm³. Oil is introduced between the blocks to cut down internal reflection and increase optical transmission. Each complete window weighs 7 tons and has shielding properties equivalent to approximately 6 ft of concrete. They were built at the Chance-Pilkington Optical Works at St. Asaphs, Flint.

(Pilkington Brothers Ltd., St. Helens, Lancashire.)

1176

CATALOGUES

A leaflet from the **Imperial Aluminium Co., Ltd.,** P.O. Box 216, Witton, Birmingham, 6, describes Impalco "Treadplate" flooring in aluminium alloy.

The Heating and Welding Department of **Associated Electrical Industries, Ltd.,** Trafford Park, Manchester, 17, has recently issued "The AEI Arc Welding Guide," which replaces previous Metrovick "Electrode Guides."

The Pitch Fibre Pipe Association of Great Britain Ltd., 27 Chancery Lane, London, W.C.2, have issued an additional leaflet to their Manual "Further Tests on Pitch Fibre Drain and Sewer Pipes."

A brochure, with many illustrations in colour describing the McFadzean Laboratory, the latest addition to the BICC research organization, has been issued by **British Insulated Callender's Cables Ltd.,** 21 Bloomsbury Street, London, W.C.1. It was produced to commemorate the official opening of the laboratory by H.R.H. the Duke of Edinburgh.

Radiovisor Parent Ltd., Stanhope Works, High Path, London, S.W.19, have issued leaflets on the QT.60 photo-electric relay, for versatile application in general industrial service.

Tracerlab Inc., 1601 Trapelo Road, Waltham 54, Mass., U.S.A., have issued a brochure on their Omni/Guard which enables low activity samples to be counted with a background of less than 0·3 c/min. Another Tracerlab publication received is the "Buyer's Guide for Scalers."

"Electri-Cand" pumps for corrosive liquids from ½ hp to 25 hp are described in a leaflet from **Allis-Chalmers Manufacturing Company (Industrial Equipment Division),** Milwaukee 1, Wisconsin, U.S.A.

The standard range of rare and base metal thermocouples for use up to 1 500°C is described in a publication issued by the **Cambridge Instrument Company Ltd.,** 13 Grosvenor Place, London, S.W.1. Another publication describes the magnetic oxygen meter.

Hilger and Watts Ltd., 98 St. Pancras Way, Camden Road, London, N.W.1, have issued section P of their catalogue, giving details of their range of crystal phosphors and crystal-photomultiplier assemblies.

Three leaflets describing Jeep, the Halden reactor and the uranium reprocessing pilot plant at Kjeller, have been received from the **Institutt for Atomenergi,** P.O. Box 175, Lilleström, Kjeller, Norway.

A leaflet issued by **Bruce Peebles and Co. Ltd.,** Edinburgh, 5, describes their resistivity meter (*Nuclear Engineering*, March, 1961, p. 125).

Ion exchange materials of all types with complete technical data and "Cellex" ion exchange celluloses, and pre-calibrated resins, are described in a brochure received from **Bio-Rad Laboratories,** 32nd and Griffin Avenue, Richmond, California, U.S.A.

From **Morganite Research and Development Ltd.,** Battersea Church Road, London, S.W.11, comes a leaflet describing "Metamic" pyrometer sheaths.

"Lead for Radiation Protection" is the title of a loose-leaf publication recently issued by **Associated Lead Manufacturers Ltd.,** London.

"Forging Close to Finished Form" (i.e. the production of forgings requiring the minimum of machining) is the subject of a booklet from **High Duty Alloys Ltd.,** Slough, Bucks.

The Brooke Tool Manufacturing Co. Ltd., Warwick Road, Greet, Birmingham, 11, have issued a publication on gear pumps, with full technical details and performance specifications of their various types.

The economies to be obtained from the use of welded stainless steel tubes are set forth in a booklet published by **Rollo-Hardy and Co. Ltd.,** Paddockhall Road, Haywards Heath, Sussex, a member of the Compoflex Group.

A leaflet received from **Alfred Imhof Ltd.,** Ashley Works, Cowley Mill Road, Uxbridge, Middx., gives details of an interesting development in economical panel framework where enclosure is not required and mobile bases on which cubicle racks may be mounted.

The English Steel Corporation Ltd., River Don Works, Sheffield, 9, have issued a revised and enlarged edition of their booklet "Engineers' Cutting Tools."

Orbits . . .

ELSEWHERE in this issue (almost as good an opening as "Once upon a time . . .") appears a letter from Dr. T. E. Allibone who—quite rightly on his reading—takes exception to remarks on the lack of frankness in the industry, made in these notes for April. Briefly—there isn't space to reprint it—we referred to the Faraday lecture, and the fact that Dr. Allibone had given both the lectures dealing with nuclear energy. We then pointed out that it would be a good idea to have a six-monthly lecture for the industry itself, given by somebody too big to be muzzled, which would Tell All—particularly about projects that were not justifying their unduly optimistic forecasts.

Our suggestions of lack of frankness were not, however, directed at scientists. Many years ago, Thomas Huxley referred to " . . . the great tragedy of Science—the slaying of a beautiful hypothesis by an ugly fact. . . " but the true scientist will accept this and, no matter what the temptation may be, will hold to the conviction that " . . . to suppress the truth is to publish a lie."

Enter £ucifer

While an individual scientist will cheerfully sacrifice himself, however, the position is a little different when it is not an individual but a team, organization or aggregation of interests, and one is dealing with a lot of men, a lot of elaborate ironmongery and a lot of money. Then, the attitude becomes a little more disingenuous . . . the Devil has entered Paradise. No more will any honest type spring up, beat his bosom and shout " It's not going to be so good as we said it was! " In the first place, it's no one's business to. In the second place, it's crying stinking fish; letting the side down; " denigrating " (ghastly word!) the National Effort . . . etc., etc. (add platitudes to taste). But in the third, fourth, fifth . . . *n*th place the position can be summed up in Stephen Leacock's simple dictum . . . " There is nothing so timid as a million dollars."

Not-so-pure Science

There is, moreover, another aspect that cannot be overlooked. The popular image of a scientist of a generation ago

> ". . . doth suffer a sea-change
> Into something rich and strange. . . . "

The lonely professor in his laboratory has given way in the public mind, to a bloke who wears a white coat and works in a vast factory. Science has become a mass-employment occupation, and the scientist is no longer necessarily a dedicated type who lives for his discoveries and nothing else. He draws a salary (usually an adequate one) he likes to knock off at 5.30, he wants social life and a shiny car like everyone else. Add to this the all-pervading " what's in it for me? " spirit that has spread through the entire fabric of society in the last couple of decades . . . you see the picture?

One looks back with awe (or derision, according to your viewpoint) on the vision of the Curies, practically on the breadline, refusing large wads of money for their radium discoveries, feeling in duty bound to publish for the benefit of humanity. Can one imagine, in this day and age, Joe Bloggins, B.Sc., working on BURP (Bolonium-Unobtainium* Reactor Project) doing likewise?

Believe it or not, one can. Not for the benefit of suffering humanity, but for the benefit of Joe Bloggins. As his discoveries (or those of his subordinates) belong to his employers anyway, there's no more money in it—so he settles for imperishable fame. He publishes . . . in his own good time. And, for the year or so that it takes to arrange the symposium (with the leading papers by Joseph Bloggins) the necessary supporting papers (with J. Bloggins in the chair) and to get everything tied up . . . and try to get any useful information about the BURP project. And let us wish you the best of luck. You'll need it!

. . . But Hard to Blame

This attitude is one which is easy to condemn in others, and very hard to resist if one is on the other end. The desire for recognition is a very human and understandable failing—so is the desire not to stick one's neck out when a cherished scheme comes unstuck. Nevertheless, we are reminded of an incident which occurred in wartime when we were attempting to divert an official row over something in which we were not involved. The answer we got was " . . . There are far too many people trying to be decent chaps around here—and we've got a war on our hands." Is there, perhaps, a parallel?

Vintage Reactor

The word " Jeep " was, originally, a corruption of " G.P." or General Purpose, applied to those apparently indestructible little vehicles that cheerfully tackled any conditions all over the world during the late international unpleasantness. In Norway, it stands for Joint Establishment Experimental Pile, but the reactor still reminds us, in its simplicity and absence of frills, of its more mobile namesake. The story of the struggle to obtain information upon which to base the design and the difficulties encountered has already been told in this column; a further instalment is given in the " Survey of Activities 1948-60 " just published by the Institutt for Atomenergi.

Originally designed for 100 kW, it was found that the output could be increased to 250 kW in the winter. New cooling arrangements increased the capacity to 800 kW, but operation is usually restricted to 450 kW because of can temperature and shielding limitations. Up to 1958 it operated without any purification plant for the heavy water—it was, as we have said, built without frills.

Nevertheless, after operating for 10 years, only 13 fuel elements have shown signs of leakage, and five have been removed for experiments. The remainder of the original 68 are still going strong. One of these days, this journal will have to emulate its motoring contemporaries and run a Vintage Reactor number. On that day, Jeep will take its rightful place, just a little astern of CP-1 Gleep and Zoe.

Be Prepared!

So, according to the Minister of Transport, we are not going to have a nuclear ship. But we *are* going to have intensive preliminary research on reactor types.

What a perfectly *splendid* idea! Why hasn't anyone thought of it before?

Administration's Artful Aid

The mysterious intricacies and multifarious ramifications (great stuff this) of the industrial complex have always held for us a certain horrid fascination, particularly as everybody's job becomes more and more specialized and their titles become more and more embelliflated until the word " executive " has come to mean practically anyone who doesn't actually push a barrow. We didn't realize, however, just how far the decentralization of control had travelled until we caught sight of an advertisement for a Salary Administrator. Now this is no new idea that someone's just dreamed up—the job calls for previous experience. Duties include management succession (whatever that is), job evaluation, salary grading, and staff assessment. We can't resist it. . . .

I have recently become Administrator
Of the salaries that all the others earn;
Though I find it very jolly
Fixing everbody's lolly
I'm so worried that I don't know where to turn.

I am very hot at Job Evaluation
And at Staff Assessment I'm no " also-ran ";
While the Management Succession
Has been my life's profession
But I'm still a very, very, worried man.

For, although I'm very good at
grading others
And apportioning the lucre, cash,
or pelf;
Though my mandate authorizes
Everybody else's rises
HOW THE DEVIL DO I GET
ONE FOR MYSELF?

Tangent

*" Unobtainium " is a name coined by the metallurgists of Atomics International for the metal required by reactor designers.